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**BOWERS LANDFILL
PICKAWAY COUNTY, OHIO
ENDANGERMENT ASSESSMENT
FINAL REPORT**

**(PRELIMINARY COPY - Subject to change as a
result of CDM FPC QA/QC review)**

Prepared for

**U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Waste Programs Enforcement
Washington, D.C. 20460**

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May 12, 1988

**Ms. Erin Moran
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**Subject: Bowers Landfill Endangerment Assessment
Final Report
TES 3 Work Assignment No. 667**

Dear Ms. Moran:

Enclosed for your review is the Bowers Landfill Endangerment Assessment, Final Report. This report replaces the draft final report previously submitted to you under the TES 3 contract (EPA Contract No. 68-01-7331, Work Assignment No. 667) on December 14, 1987. The final report incorporates changes made by PRC in response to comments from U.S. EPA Region 5, Ohio EPA, potentially responsible parties, and the public. The report also includes new sampling data from samples taken in March 1988.

The final report was prepared under the TES 3 contract. This report has not been reviewed by the TES 3 prime contractor, CDM Federal Programs Corporation, and is subject to change pending the results of the quality assurance/quality control review to be conducted by CDM FPC. CDM has reviewed the December 14 draft final report and all comments.

At your request, PRC is submitting copies of the final report to a number of persons including members of the Bowers Landfill Information Committee, Ohio EPA, the potentially responsible parties (E.I. Dupont de Nemours & Co. and PPG Industries, Inc.), and the PRP contractor (Dames & Moore).

Please contact me at 312/856-8700 if you have any questions concerning this endangerment assessment report.

Sincerely,

Eric J. Moran
for John Dirgo
Environmental Scientist

cc: Daniel Chow, PRC
Harry Butler, CDM FPC
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LIST OF ACRONYMS/ABBREVIATIONS

<u>Acronym</u>	<u>Description</u>
AHH	aryl hydrocarbon hydroxylase, a liver enzyme which oxides PAHs
AIC	Acceptable Intake for Chronic Exposure, used in calculation of hazard indices
AWQC	Ambient Water Quality Criteria, guidelines established by U.S. EPA under Clean Water Act
BAP	benzo(a)pyrene, a PAH
BCF	Bioconcentration Factor, indicates tendency of a chemical to bioaccumulate
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, formal name for Superfund
CLP	Contract Laboratory Program
CRDL	Contract Required Detection Limit
Dioxin	2,3,7,8-tetrachlorodibenzo-p-dioxin
E_h	Oxidation - Reduction Potential
H	Henry's Law Coefficient, indicates a chemical's potential for volatilization
HA	Health Advisories, established by U.S. EPA Office of Drinking Water based on noncarcinogenic effects
HI	Hazard Index, used to evaluate health risks for noncarcinogenic indicator chemicals
IS	Indicator Score, used in selecting indicator chemicals according to SPHEM
K_{oc}	Sorption Coefficient, used for ranking and comparing a chemical's potential for leaching
K_{ow}	Octanol/Water Partition Coefficient, used in calculating K_{oc} (also see Appendix B)
LC_{50}	Concentration of a chemical causing death in 50 percent of the organisms in an exposed test group
MCL	Maximum Contaminant Level(s), enforceable drinking water standards for public water supply systems by EPA under Safe Drinking Water Act
NAAQS	National Ambient Air Quality Standard

<u>Acronym</u>	<u>Description</u>
NPL	National Priorities List, sites slated for EPA enforcement action or cleanup under Superfund
ODNR	Ohio Department of Natural Resources
OEPA	Ohio Environmental Protection Agency
PAH	polynuclear aromatic hydrocarbon(s)
PCB	polychlorinated biphenyl(s)
p-cresol	para-cresol; 4-methylphenol, a cresol isomer
PRP	Potentially Responsible Party
RI/FS	Remedial Investigation/Feasibility Study, investigates scope of contamination and remedial alternatives for Superfund sites
RL	Reference Level, used in calculating HIs
SPHEM	Superfund Public Health Evaluation Manual
SVOC	Semivolatile Organic Compound(s)
TLV	Threshold Limit Value(s), established by American Conference of Governmental Industrial Hygienists to protect workers during normal work hours
VOC	Volatile Organic Compound(s)

EXECUTIVE SUMMARY

This report assesses the endangerment associated with contaminants at or released from Bowers Landfill to the environment. Bowers Landfill, located in Pickaway County, Ohio, approximately 2.5 miles north of the City of Circleville, received various types of hazardous and nonhazardous wastes between 1958 and 1968. From 1958 to 1963, the site operated as a landfill with the majority of the waste it received coming as residential refuse collected by the City of Circleville. From 1963 to 1968, the site also received chemical wastes from local industries including the E.I. Dupont deNemours & Company (Dupont) and Pittsburgh Plate Glass (now PPG Industries, Inc.). Wastes were disposed of at the site by dumping directly onto the ground and covering the wastes with dirt. Some excavation for waste disposal may also have occurred. In addition, some wastes were burned at the site. The landfill is inactive at the present time.

Beginning in the early 1980s, several events took place which brought increased attention to the site. In 1982, after significant levels of organic contaminants were measured in water samples from the site, the Ohio Environmental Protection Agency (OEPA) requested that the landfill be placed on the National Priorities List (NPL) as a Superfund site. In 1985, U.S. EPA and OEPA signed a consent order with Dupont and PPG Industries, Inc., two of the potentially responsible parties. This order outlined the scope and schedule for a remedial investigation/feasibility study at Bowers Landfill.

The endangerment assessment is based in large part on data collected during the remedial investigation at the site. The nature and extent of risks to human health and the environment posed by the site are characterized in the endangerment assessment, and will guide the selection and evaluation of remedial alternatives during the feasibility study. In particular, the objective of this endangerment assessment was to determine the magnitude and probability of actual or potential harm to public health, welfare, and the environment posed by the actual or potential releases of hazardous substances from Bowers Landfill. PRC accomplished this objective by evaluating several factors, including the existing extent of contamination in various environmental media; the potential for contaminants to migrate within and between media; the environmental persistence and toxicity of the contaminants; site-specific factors that influence possible routes of human and

environmental exposure to contaminants; populations that could be exposed to contaminants; and the potential risks resulting from exposure.

Based on our review of the available data, PRC determined that Bowers Landfill has released and may continue to release contaminants to the environment. In fact, over 40 contaminants have been identified in ground water, surface water, soils, and sediments at or near the site. However, it should be understood that not all of these contaminants may have been released from the landfill.

PRC evaluated these contaminants for their toxicity, and fate and transport properties, and identified 9 indicator contaminants -- benzene, polynuclear aromatic hydrocarbons (PAH), chlordane, 4-methylphenol, polychlorinated biphenyls (PCB), tetrachloroethane, barium, lead, and mercury. The major environmental release mechanisms for these contaminants were determined to be leachate migration to the ground water and surface water, surface runoff to the surrounding soils, soil erosion, and particulate generation.

Next, PRC evaluated the site information and identified processes that may influence the fate and transport of the indicator contaminants to the environment and reached four general conclusions. First, benzene, tetrachloroethane, and 4-methylphenol may move into ground water as leachate from Bowers Landfill. These compounds are then expected to move with bulk ground-water flow. However, only benzene thus far has been detected in ground water at higher concentrations downgradient of the landfill than upgradient. In contrast, chlordane, PCBs, and polynuclear aromatic hydrocarbons (PAHs) are expected to sorb to substrate particles or precipitate and thus move more slowly than the bulk flow. It should be noted that none of these compounds have been detected in any downgradient ground-water samples near Bowers Landfill.

Second, the volatile organics will volatilize from the surface water and soil to the atmosphere. To date, only tetrachloroethane has been detected in upstream or downstream surface water samples (at similar concentrations). In addition, PCBs (not normally classified as a volatile organic) measured in on-site soil samples may also volatilize to some degree.

Third, barium, lead, mercury, chlordane, PCBs, and PAHs measured in higher concentrations in samples on or adjacent to the landfill than in background samples, are expected to sorb strongly to soil particles. Transport of these compounds is expected to occur largely through soil erosion and particulate generation.

Finally, in the surface waters, the inorganics (with the possible exception of lead), chlordane, PCBs, and PAHs will tend to sorb to particulates and be deposited in the sediments. Under expected pH conditions of natural surface water, lead may exhibit some degree of mobility due to forming soluble complexes with several inorganic anions.

PRC also reviewed and evaluated the toxicity data on the indicator contaminants. From the review, we determined that benzene is a known human carcinogen, and PAHs, chlordane, PCBs, and tetrachloroethane are potential human carcinogens. All the indicator contaminants elicit toxic noncarcinogenic responses in humans. Chlordane, PCBs, lead, and mercury exhibit the highest toxicity to aquatic life. During this review, PRC also identified standards and criteria established by U.S. EPA to protect human health and the environment under various exposure routes. PRC used these standards and criteria in characterizing the potential risk from site releases.

PRC established 10 potential exposure scenarios for contaminants at or released from the site and identified the potentially exposed populations; these are summarized in Table ES-1. PRC evaluated the potential risks associated with each of these scenarios for the identified populations. Potentially significant risks identified for Bowers Landfill are summarized in Table ES-2. Where possible, PRC looked at worst case (maximum contaminant concentrations) and probable case (geometric mean contaminant concentrations) conditions.

From these risk characterizations, PRC concluded that under a limited number of exposure scenarios, the nature and extent of contamination found on or surrounding Bowers Landfill presents potential risks to human health and the environment. Carcinogenic risks for ingestion of ground water (potential future exposure) and soil by humans fall within the target risk range of 10^{-4} to 10^{-7} . There are also potential noncarcinogenic risks for these exposure scenarios, since hazard indices exceed one. Incidental ingestion of surface water and ingestion of

TABLE ES-1

POTENTIAL EXPOSURE SCENARIOS AND EXPOSED POPULATIONS
ASSOCIATED WITH BOWERS LANDFILL

	<u>Exposure Scenario</u>	<u>Exposed Population</u>
1)	Ingestion of contaminated ground-water	Future users of the upper and lower aquifers downgradient (west) of the landfill.
2)	Direct contact with or incidental ingestion of contaminated surface water	Recreational users of the site, adjacent quarries, or the Scioto River
3)	Direct contact with contaminated sediment	Recreational users of the site, adjacent quarries, or the Scioto River
4)	Ingestion of contaminated aquatic organisms from the Scioto River	Recreational users of the Scioto River
5)	Direct contact with or ingestion of contaminated soils	Recreational users of the site and adjacent fields and agricultural workers in adjacent fields.
6)	Inhalation of contaminated air	Recreational users of the site and adjacent fields and agricultural workers in adjacent fields
7)	Ingestion of contaminated crops	General public
8)	Ingestion of contaminated terrestrial animals and birds	Recreational users of the site, adjacent fields, and the Scioto River
9)	Direct contact with or ingestion of contaminated surface water and sediments by aquatic life	Aquatic populations in the Scioto River
10)	Ingestion of contaminated plant life by terrestrial animals and birds	Terrestrial populations at the site and adjacent fields and avian populations nesting near the site

TABLE ES-2
SUMMARY OF POTENTIALLY SIGNIFICANT RISKS
IDENTIFIED FOR BOWERS LANDFILL
(Page 1 of 2)

<u>Exposure Route</u>	<u>CA/NCA</u> ¹	<u>Contaminants</u>	<u>Risk Assessment</u> ²	<u>Comments</u>	<u>Section Reference</u>
1. Ingestion of Ground Water	NCA	Barium	Hazard Index ³ = 1.04	While based on the maximum barium concentration, the hazard index only slightly exceeds unity. Therefore, the actual noncarcinogenic risk via this scenario is probably very small.	5.1
	CA	Benzene	Incremental Carcinogenic risk = $9\text{E-}06$ (worst case), $1\text{E-}06$ (probable case)	The incremental carcinogenic risks for benzene are within the target range of 10^{-6} to 10^{-7} (see footnote No. 4).	
2. Ingestion of Surface Water	CA	PCBs	Maximum PCB concentration in the drainage ditches (2.6 ug/l) exceeds the ambient water quality criteria (AWQC) for consumption of drinking water alone corresponding to a 10^{-6} cancer risk (0.012 ug/L).	The AWQC for PCBs used here assumes a lifetime exposure while this scenario assumes infrequent incidental ingestion, therefore, this risk assessment overestimates the actual risk.	5.2
3. Ingestion of Aquatic Animals	NCA	Mercury	The maximum mercury concentration (0.2 ug/L) exceeds the AWQC based on ingestion of aquatic animals alone (0.1465 ug/L).	Tissue samples have not been taken to verify the extent of this exposure. Further, average mercury concentrations were below the AWQC and mercury was found in only one surface water sample from the Scioto River. Thus, this risk is limited.	5.4

ES-5

TABLE ES-2 (continued)

Exposure Route	CA/NCA ¹	Contaminants	Risk Assessment ²	Comments	Section Reference
4. Ingestion of Soils	NCA	Lead	Hazard Index = 3.20	This hazard index may overestimate the actual risk because it assumes both the maximum lead concentration and a worst case soil ingestion rate. Further, lead levels in on-site soils are below CDL guidelines for residential areas.	5.5
	CA	Total PAHs	Incremental Carcinogenic Risk = 2E-06	These two risks may overestimate the actual risk because they are based on maximum concentrations and a worst case soil ingestion rate. See also Footnote No. 3.	
		PCBs	Incremental Carcinogenic Risk = 7E-07		
5. Direct Contact with Surface Water by Aquatic Animals	NCA	Mercury	Maximum mercury concentration (0.2 ug/L) exceeds the 4-day AMOC for protection of aquatic life (0.012 ug/L).	Actual risk may be negligible based on average mercury concentrations. Further mercury was found in only one surface water sample from the Scioto River.	5.9

Notes:

1 CA = Carcinogenic
NCA = Noncarcinogenic

2 These risks as well as those risks for the remaining exposure scenarios are discussed in detail in the body of the endangerment assessment.

3 The hazard index (HI) is calculated as the ratio of exposure dose to acceptable dose; an HI > 1 indicates a potentially significant risk.

4 EPA guidance (U.S. EPA, 1987a) described a carcinogenic risk target range (10^{-6} to 10^{-7}). Risks greater than 10^{-6} are considered "significant", while risks < 10^{-7} are considered insignificant. Risks between 10^{-6} and 10^{-7} are within the target range, their significance will in general reflect site specific factors.

aquatic organisms could also pose potential risks to human populations. Aquatic organisms are also potentially at risk due to contaminant concentrations in the Scioto River.

CHAPTER 1

INTRODUCTION

Bowers Landfill, also known as the Island Road Landfill, is located in Pickaway County, Ohio, on the eastern edge of the Scioto River valley. Between 1958 and 1968 or 1969, municipal and hazardous waste was disposed of at the site (Burgess & Niple, 1981). According to information on file with the Ohio Environmental Protection Agency (OEPA), the majority of waste materials consisted of residential refuse collected by the City of Circleville, as well as by several private haulers in the Circleville area. In addition, reports indicate that wastes from at least three manufacturing plants and two grain elevators were disposed of at Bowers Landfill. Although the site ceased operations in 1968 or 1969, evidence of continued waste disposal has been observed along a bluff, immediately east of the landfill, during site visits by U.S. EPA and other investigators. Upon investigation by U.S. EPA and OEPA, several water samples were collected and found to contain significant levels of organic contaminants. In 1982, OEPA requested that the landfill be placed on the National Priorities List (NPL) as a Superfund site (CH2M Hill, 1983). [Note: A list of acronyms and abbreviations used in this report is included after the Reference section.]

PRC Environmental Management, Inc., received Work Assignment No. 667 under U.S. EPA Contract No. 68-01-7331 (TES 3) to perform feasibility study (FS) oversight and to finalize a draft endangerment assessment for Bowers Landfill. PRC performed remedial investigation (RI) oversight and prepared the draft endangerment assessment under an earlier U.S. EPA contract (TES 2). PRC is submitting this report to meet the endangerment assessment requirements of Work Assignment No. 667.

The objective of this endangerment assessment was to determine the magnitude and probability of actual or potential harm to public health, welfare, and the environment posed by the actual or threatened releases of hazardous substances from Bowers Landfill. An endangerment assessment accomplishes this objective by evaluating the collective demographic, geographic, physical, chemical, and biological factors that determine the impact of an actual or potential release of hazardous substances from a site. U.S. EPA generally requires an endangerment assessment to

support all administrative and judicial enforcement actions under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).

Section 300.68 of the National Contingency Plan requires that a remedial investigation (RI) and feasibility study (FS) be performed for hazardous waste sites that may require cleanup. The endangerment assessment is an interpretive link between the RI and FS. The endangerment assessment can help determine (1) the threats to potentially affected populations and environments posed by hazardous substances, and (2) remedial actions that can be considered to abate these threats.

Preparation of an endangerment assessment requires an evaluation of several factors, including the existing extent of contamination in various environmental media; the potential for contaminants to migrate within and between media; the environmental persistence and toxicity of the contaminants; site-specific factors that influence possible routes of human and environmental exposure to contaminants; populations that could be exposed to contaminants; and potential risks resulting from exposure. The following paragraphs briefly outline the steps that PRC followed in preparing the risk assessment for Bowers Landfill and the information contained in this report.

The remainder of Chapter 1 presents background information on Bowers Landfill, including the site history and a description of disposal practices. Chapter 1 also identifies contaminants that have been found in soil, ground-water, surface water, and sediment samples collected from the landfill and surrounding locations. Finally, Chapter 1 selects nine indicator chemicals that will be evaluated in subsequent chapters. The selection procedure is designed to identify the "highest risk" chemicals at Bowers Landfill so that the endangerment assessment focuses on the chemicals of greatest concern.

Chapter 2 discusses the fate and transport of indicator chemicals in the environment. It reviews the physical and chemical properties of each indicator chemical and evaluates how these properties affect the movement of chemicals through different environmental media (soil, ground water, surface water, sediment, or air). Chapter 2 also discusses specific characteristics of the Bowers Landfill site that affect the fate and transport of indicator chemicals. These characteristics include climate and the geologic and hydrogeologic features of the site. The

identification of potential migration pathways leads directly into the assessment of potential exposure routes.

The third chapter of the endangerment assessment evaluates the likelihood of exposure to indicator chemicals at Bowers Landfill. This chapter identifies human and animal populations near the site. It also describes different scenarios that could cause these populations to be exposed to chemicals potentially released from the landfill. In cases where sufficient information is available, the chapter presents quantitative estimates of exposure (mg of contaminant taken in by the body per kg of body weight per day of exposure). Where sufficient information is not available, the chapter presents a qualitative evaluation of exposure. The exposure assessment in Chapter 3 identifies the most significant routes of exposure and serves as the basis for the risk assessment in Chapter 5.

Chapter 4 evaluates the toxicologic properties of indicator chemicals. The chapter is not intended to be a comprehensive review, but rather a summary of indicator chemical toxicology in light of the potential exposure routes at Bowers Landfill. The chapter presents basic information on how chemicals are absorbed, metabolized, and excreted by the body. It also identifies potential acute and chronic health effects caused by exposure to each chemical. Finally, the chapter describes applicable standards and guidelines for exposure to each indicator chemical. Standards and guidelines include acceptable drinking water concentrations and occupational exposure limits.

Chapter 5 characterizes the potential risks due to exposure to indicator chemicals released from Bowers Landfill. For some exposure routes, only a qualitative characterization of risks is possible. For other exposure routes, a quantitative risk characterization can be made by comparing exposure estimates from Chapter 3 with standards and guidelines from Chapter 4. The quantitative risk assessment for carcinogenic indicator chemicals is expressed as a probability of developing cancer from exposure to the chemicals. Noncarcinogenic chemicals are evaluated by comparing estimated exposure levels with published guidelines for acceptable exposure.

Finally, Chapter 6 summarizes the results of the preceding chapters. The

chapter briefly describes each potential exposure route and summarizes potentially significant risks.

Chapter 6 also discusses some of the uncertainties involved in the exposure and risk estimates for Bowers Landfill and reiterates some of the assumptions used to develop these estimates.

1.1 BACKGROUND

The following sections discuss the location, description, and history of Bowers Landfill.

1.1.1 Site Location

Bowers Landfill is located in rural Pickaway County, Ohio, approximately 2.5 miles north of the City of Circleville (see Figure 1-1). The site is just northwest of the intersection of Island Road and Circleville - Florence Chapel Road, on the east side of the Scioto River valley.

The landfill lies within the Scioto River floodplain. Its northwestern- and southernmost points abut the river (see Figure 1-2). The north and west side of the landfill is bordered by cultivated fields. Several inactive quarries and an active quarry lie immediately to the east and northeast of the landfill, respectively. These areas have been quarried from an upland area, but in places they extend to a depth below that of the landfill berm.

1.1.2 Site Description

Bowers Landfill occupies about 12 acres of a 202-acre tract owned by the estate of Dr. John M. Bowers. The landfill was constructed as a berm 4,000 feet long with an average width of 125 feet and a top height of 6 to 10 feet above grade. The landfill has a reported waste volume of about 130,000 cubic yards (Burgess & Niple, 1981). The landfill is inactive; it has not received any wastes since it stopped operating in 1968 or 1969. Wastes placed in the landfill were covered with soil, but the landfill surface is not capped. There is a vegetative

FIGURE 1-1 SITE VICINITY MAP

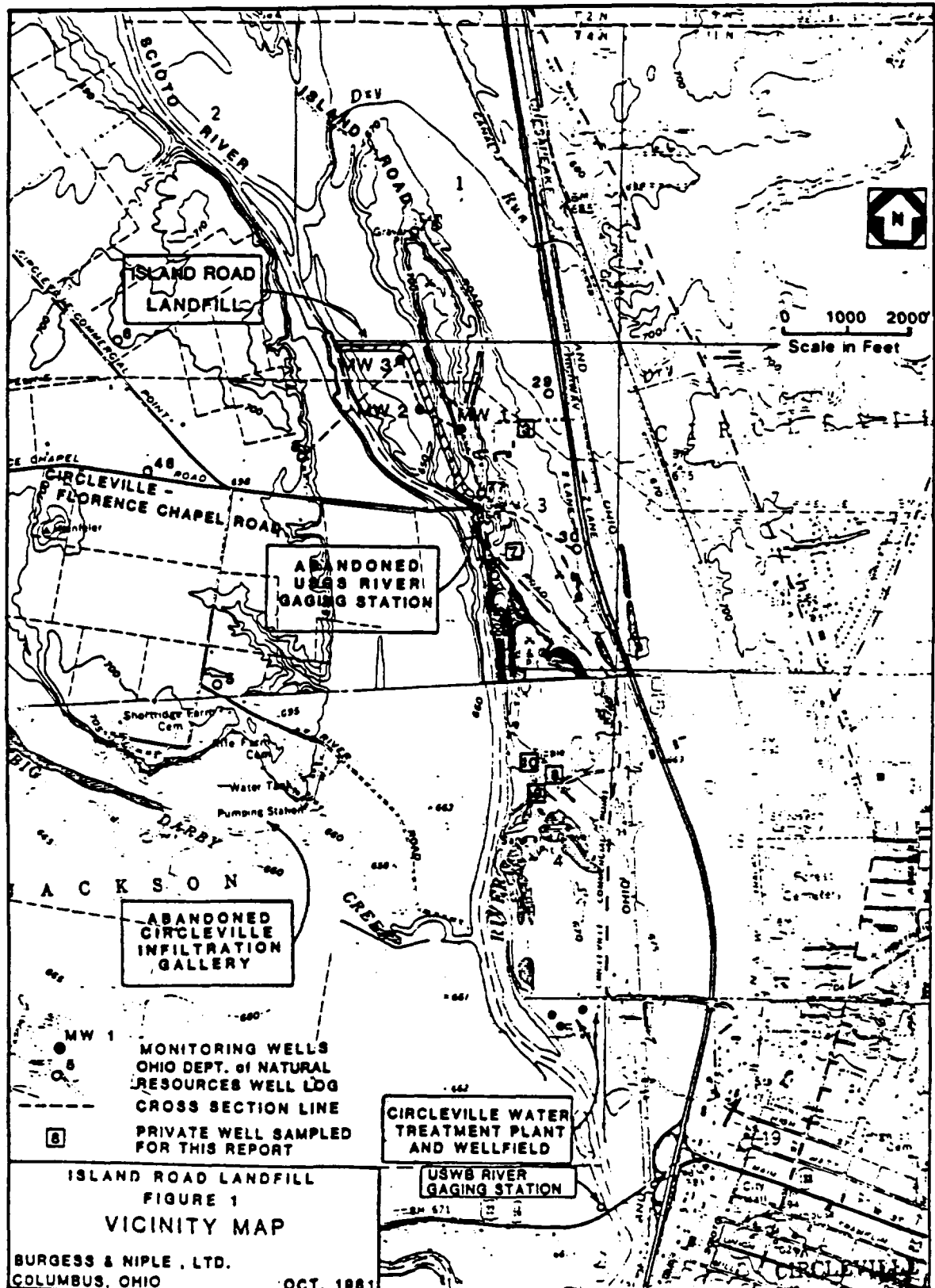
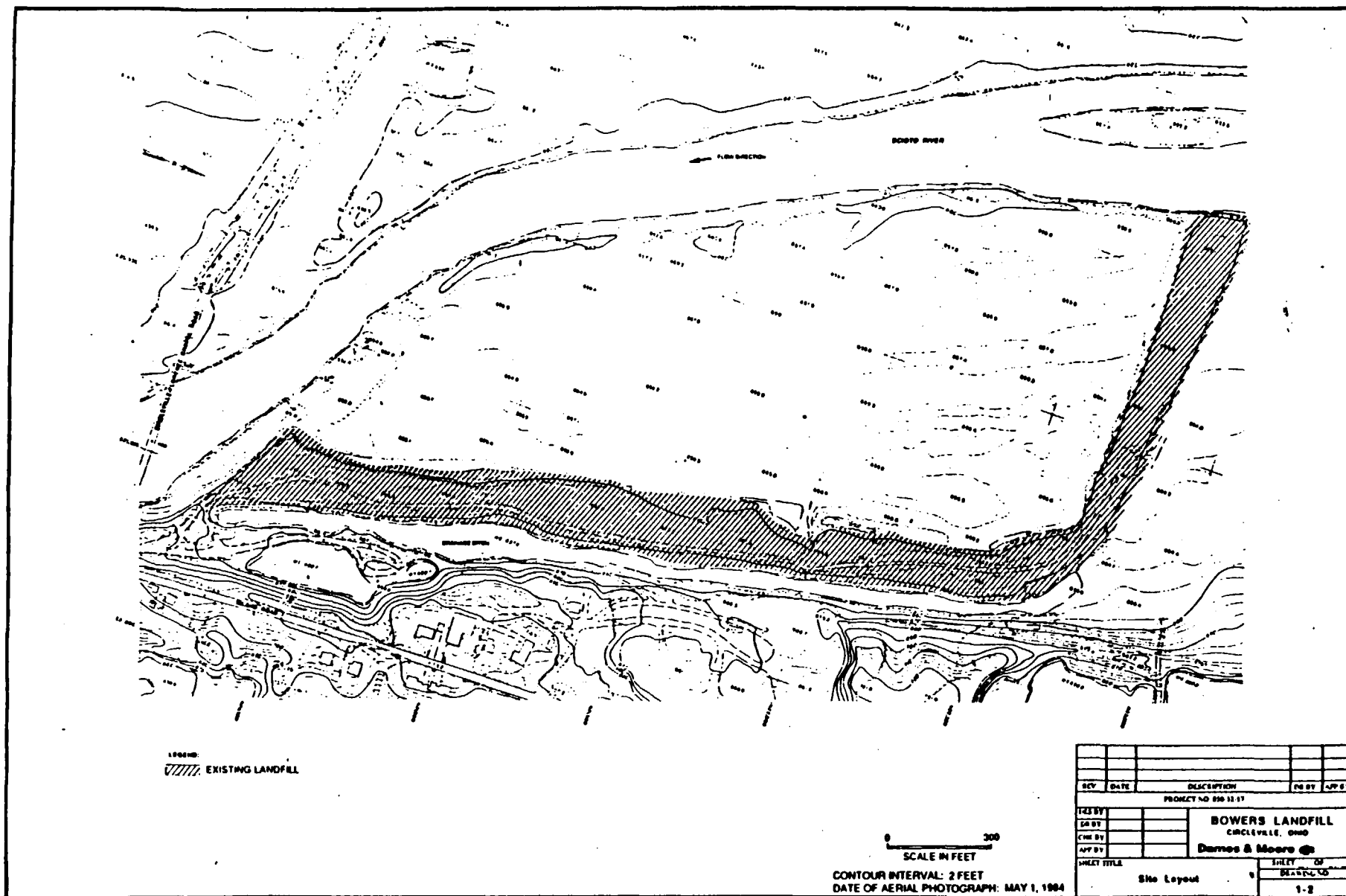


FIGURE 1-2 SITE PLAN



Source: Dames & Moore, 1987a

cover of underbrush, grasses, and small trees over most of the landfill. In spite of the vegetative cover, small portions of the landfill have been eroded by runoff and flood events. Plastic sheeting, drums, reaction vessels, and other industrial debris and refuse are exposed in some areas of the landfill. An unpaved road runs along the top of the landfill. A portion of this road is used to gain access to the cultivated field between the landfill and the Scioto River. The road is used infrequently and is overgrown with vegetation.

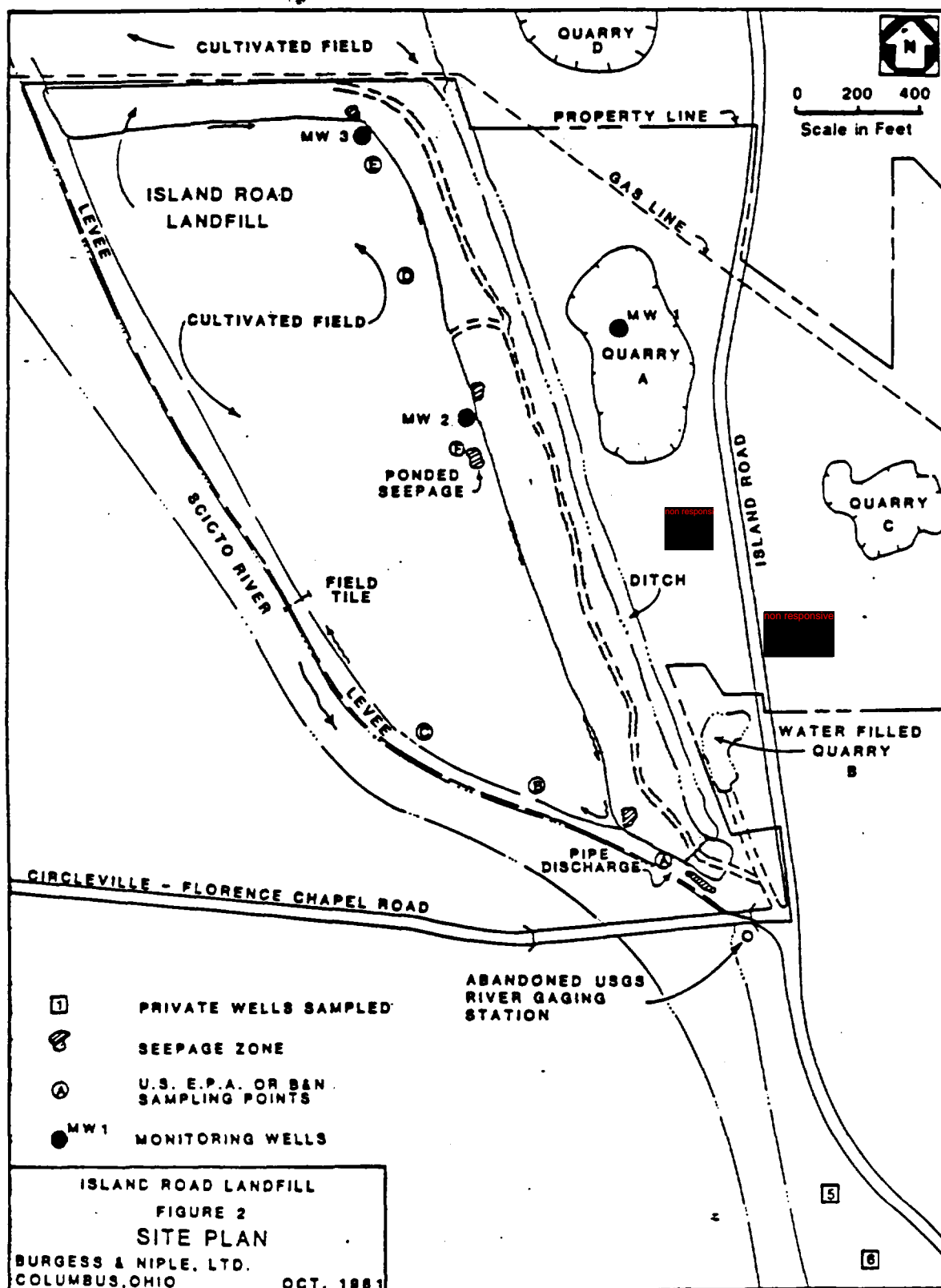
Surface runoff from the site is generally to the west and south toward the Scioto River. Two ditches parallel the landfill along its length. One ditch runs south on the west side of the landfill; the other ditch runs south along the east side of the landfill. The ditch on the west side of the landfill is not well developed and does not discharge to the Scioto River. Instead, flow appears to pond near the southern end of the landfill during wet periods (Dames and Moore, 1987a).

The ditch on the east side of the landfill generally flows southward to a ponded area near the south end of the landfill, and then by pipe under the landfill to a discharge point at the Scioto River. However, this east ditch also opens northward into an intermittent pond that abuts the cultivated field. During high flow events, this ditch probably also discharges northward to the intermittent pond and the adjacent field.

The ditches are not well developed along the east-west leg of the landfill. Most site runoff from these portions of the landfill will discharge directly to the adjacent fields.

There are four quarried areas adjacent to the landfill (Burgess & Niple, 1981). These are shown as quarries A, B, C, and D on Figure 1-3. Quarry D is an active quarry, and quarries B and C are inactive. Quarry A was inactive during the period of remedial investigation field work; however, the Sturm and Dillard Company recently acquired quarry A and intends to continue quarrying activities near Bowers Landfill (Leyden, 1986; Petroccia, 1988). A fifth quarry contains a large body of standing water and is located approximately 1/2 mile south of Bowers Landfill.

FIGURE 1-3 QUARRIED AREAS NEAR BOWERS LANDFILL



The sand and gravel deposits east of the landfill also support small internal drainage areas where water may accumulate at the points of deeper excavation on a yearly basis. During flood events (twice in 1986), quarry B on Figure 1-3 was observed by oversight personnel to be flooded and hydraulically connected with water in the east landfill ditch.

Leachate and seeps have reportedly been observed from the sides of the landfill (Burgess & Niple, 1981). However, Dames & Moore indicated that very little evidence of leachate or seeps was observed during recent site visits (Dames & Moore, 1987b). One area of persistent seepage at the southwest corner of the landfill was observed during remedial investigation oversight activities in 1986 and 1987.

1.1.3 Site History

Bowers Landfill is named after Dr. John M. Bowers, D.D.S., of Circleville, Ohio, who purchased the site in June 1957 (Burgess & Niple, 1981). Aerial photographs of the site (dated 1951 and 1958) show that the land was used for farmland and woodland prior to the active period of the landfill (Burgess & Niple, 1981).

Dr. Bowers began operating the landfill in 1958. No industrial dumping at the site was reported before 1963. Between 1963 and 1968, in addition to general domestic and industrial refuse, the site received chemical wastes originating from local industries, including E.I. Dupont de Nemours & Company (Dupont) and Pittsburgh Plate Glass (now PPG Industries, Inc.).

Waste disposal practices consisted of dumping waste material directly onto the ground and covering it with soil from the adjacent quarrying operation (Burgess & Niple, 1981). However, there is some indication that excavation for waste disposal may have occurred in the southern part of the landfill (Dames & Moore, 1987a). Waste was also burned at the site; at least four "cease burning" orders were issued to Dr. Bowers in 1963 (Burgess & Niple, 1981). The extent of waste burning activities and the period that they occurred are not known. Landfilling at the site ended around 1968.

In 1980, U.S. EPA collected surface water samples from the site area. Results of these samples indicated that some contaminants were being released from the landfill. U.S. EPA subsequently required Dr. Bowers to commission an environmental study of the site (CH2M Hill, 1983). Burgess & Niple was hired to install three monitoring wells and to sample these and a number of existing private wells and surface water points near the site. The analytical results of these samples indicated the release of volatile organic contaminants (VOC) to surface water and ground water. Ethylbenzene, toluene, and xylene were found in downgradient monitoring wells immediately west of the landfill. However, no VOCs were detected in an upgradient monitoring well approximately 250 feet east of the landfill, three residential wells 300 to 550 feet east of the landfill, two residential wells approximately 1,000 feet south of the landfill, or five other residential wells farther to the east or south (Burgess & Niple, 1981).

In 1985, U.S. EPA and OEPA signed a consent order with DuPont and PPG, two of the potentially responsible parties (PRP) (U.S. EPA, 1985a). This consent order outlined the scope of and schedule for a remedial investigation/feasibility study (RI/FS). The PRPs contracted Dames & Moore to conduct the RI. Most RI field work was conducted from July 1986 to May 1987. Dames & Moore conducted a supplemental RI field investigation during February and March 1988. Field activities included a geophysical survey, installation of 20 monitoring wells, abandonment of Burgess & Niple wells, three rounds of ground-water sampling, two rounds of surface water and sediment sampling, and two rounds of soil sampling. Dames & Moore submitted to U.S. EPA and OEPA a draft remedial investigation report dated July 30, 1987. Dames & Moore has since submitted two revised versions of the RI report, the first on November 18, 1987 (Dames & Moore, 1987a) and the second on April 28, 1988 (Dames & Moore, 1988). Work on the RI/FS is ongoing.

1.2 WASTE MATERIALS DISPOSED OF AT BOWERS LANDFILL

Very little information is available on the types of waste disposed of at Bowers Landfill. Most available information was supplied from Burgess & Niple and Dames & Moore interviews of persons familiar with former site activities. However, these interviews were conducted at least 13 years after landfilling operations ended. This and other available information is presented below.

According to OEPA files, waste disposed of at the site primarily consisted of residential type wastes collected by private haulers in and around the Circleville area. A 1967 report by the Ohio Department of Health estimated that about 150 open truckloads of waste were received at the site every month (Burgess & Niple, 1981). The Ohio Department of Health estimated that about 40 percent of this waste was generated by industries. Waste materials included liquids in tank trucks and drums. These materials were reportedly dumped on the ground surface in the north central area of the north-south leg of the landfill (Adelsberger, 1986). The major generators cited were Dupont and PPG (Burgess & Niple, 1981).

Little information is available on the types of waste disposed of by these parties at Bowers Landfill. However, a 1978 report by the House Subcommittee on Oversight and Investigation, chaired by Representative Robert C. Eckhardt, lists the wastes disposed of by Dupont and PPG. The subcommittee conducted the investigation to determine (on a national basis) the types of wastes being generated and the means of disposal being used. Table 1-1 lists the data provided by Dupont and PPG in response to the Eckhardt subcommittee questionnaires. It should be noted that this survey was limited to industry-compiled information, and no attempt was made to verify this information. Also the report did not identify the amounts of individual waste streams that were disposed.

1.2.1 E.I. DuPont de Nemours & Company

E.I. DuPont de Nemours & Company (DuPont) began operating in Circleville in 1954. Dupont reported dumping a total of 6,000 tons of industrial waste at Bowers Landfill from 1965 to 1968 (see Table 1-1). This waste included mylar and plastic, liquids in tank trucks that were dumped on the ground surface, barrels containing unknown material, and hot plastics that solidified when cooled (Burgess and Niple, 1981).

1.2.2 PPG Industries, Inc.

PPG's Circleville plant was established in 1962. Wastes reported as originating at PPG included barrels containing unknown substances and liquids in tank trucks. Many of the barrels were reportedly buried with their contents. PPG estimated that

TABLE 1-1
COMPOSITION OF WASTE FROM THE ECKHARDT REPORT

<u>Generator</u>	<u>Composition of Waste</u>
E.I. DuPont de Nemours & Company	Heavy metals and trace metals (bonded organically and inorganically) Arsenic, selenium, and antimony Iron, magnesium, and manganese Zinc, cadmium, copper, and chromium Organics Amides, amines, and imides Resins Elastomers Solvents, polar (except water) Halogenated aliphatics Acrylates and latex emulsions Solvents, halogenated aliphatic Oils and oil sludges Esters and ethers Alcohols Ketones and aldehydes Inorganics Salts Paints and pigments Asbestos
PPG Industries Inc.	Organics Halogenated aliphatics Halogenated aromatics Acrylates and latex emulsions Amides, amines, and imides Plasticizers Resins Elastomers Solvents, polar (except water) Trichloroethylene Other solvents, nonpolar Solvents, halogenated aliphatic Oils and oil sludges Esters and ethers Alcohols Dioxins Inorganics Salts Mercaptans Wastes with flash point below 100 °F

Source: Burgess & Niple, 1981

it sent 1,700 tons of waste (see Table 1-1) to Bowers Landfill between 1965 and 1968 (Burgess & Niple, 1981).

1.3 DETECTED CONTAMINANTS

This section discusses contaminants detected at and in the vicinity of Bowers Landfill. These contaminants were detected in one or more of the following environmental media: ground water, surface water, sediment, and soil. Several sampling events have occurred at Bowers Landfill since 1980. These include sampling events conducted prior to the RI and sampling events conducted as part of the RI. PRC refers to data resulting from pre-RI sampling as old data; data collected as part of the RI is considered new data. This section presents a brief overview of old data and a more complete discussion of new data.

1.3.1 Detected Contaminants -- Old Data

Three groups conducted sampling activities at Bowers Landfill prior to the RI: U.S. EPA, Burgess & Niple, and Ohio EPA. These sampling activities are listed below.

- o In July 1980, U.S. EPA collected five surface water samples near Bowers Landfill. Several volatile organic compounds were detected in these samples. Sample locations and analytical results (taken from Dames & Moore, 1987a) are presented in Appendix A to this report.
- o In 1981, Burgess & Niple collected ground-water samples from three monitoring wells and surface water samples from two locations at Bowers Landfill. Several volatile organic, semivolatile organic, and inorganic contaminants were detected in all three wells. Samples from both surface water locations contained semivolatile and inorganic contaminants, but no volatile organic contaminants. Sample locations and sample results (taken from Dames & Moore, 1987a) are presented in Appendix A to this report.
- o In May 1982 and May 1983, Ohio EPA collected several leachate and ponded water samples. The analyses of these samples revealed the presence of volatile organic compounds in both media. The sampling locations were either on or adjacent to the landfill. Analytical data from these samples were obtained from OEPA (Ohio Department of Health, 1982; 1983) and are summarized in Appendix A to this report.

As directed by U.S. EPA, this endangerment assessment does not consider these data in evaluating potential risks associated with Bowers Landfill. There are two primary reasons for this decision. First, since these data are from 5 to 8 years old, they do not reflect current contaminant concentrations at Bowers Landfill. Second, PRC is unsure of the validity of the old data because the methods and procedures used to collect the data and to assure the quality of that data are not known.

1.3.2 Detected Contaminants -- New Data

Dames & Moore, a contractor to DuPont and PPG, sampled ground water, surface water, sediment, and soil during the RI. The first sampling round for ground water, surface water, and sediment took place between February 9 and February 15, 1987. The second sampling round for these media occurred between April 27 and May 1, 1987. The first sampling round for soil was conducted between September 23 and September 25, 1986. U.S. EPA collected one or more split samples from each medium during each sampling round.

At the request of U.S. EPA and OEPA, Dames & Moore conducted supplemental RI field activities in February and March 1988. These activities included installation of two deep monitoring wells east of the landfill, a third round of ground-water sampling on March 3, and a second round of soil sampling on March 2. The additional sampling activities were limited. Some new locations were sampled; however, most of the locations sampled in earlier rounds were not resampled. U.S. EPA did not collect split samples during these sampling rounds.

All samples collected during the RI (Dames & Moore samples and U.S. EPA split samples) were analyzed by laboratories that participate in the U.S. EPA Contract Laboratory Program (CLP). Analyses were conducted according to standard CLP procedures. Analytical data were checked and validated to ensure that CLP quality assurance/quality control requirements were met.

This section summarizes the RI sampling results (complete results are presented in Appendix A). In this section, and throughout this report, PRC focuses on data that have been judged to be valid. In doing so, we have adhered to the following guidelines:

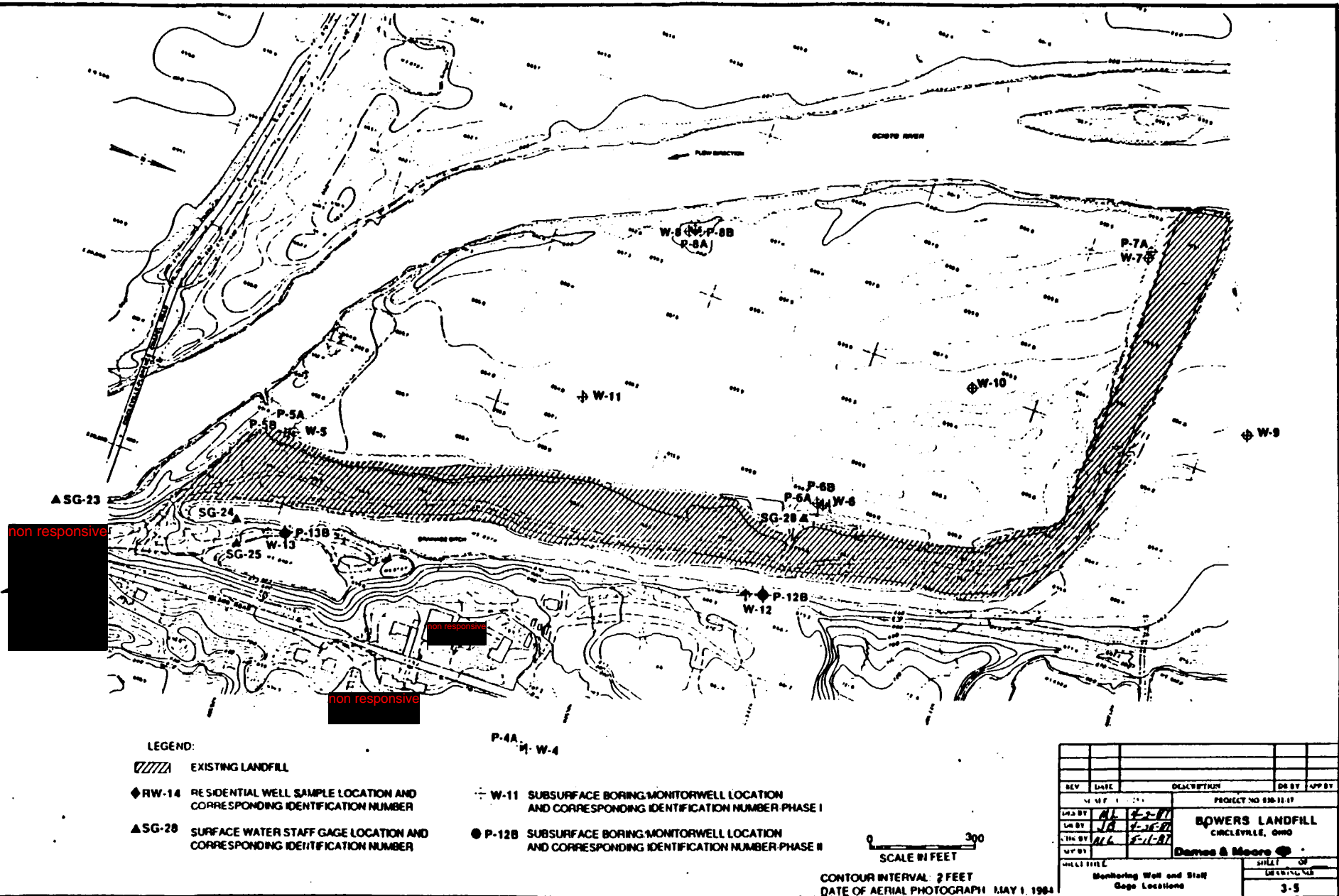
- o PRC disregarded all results where the presence of a chemical was identified by a laboratory report as due to field or laboratory contamination of a sample.
- o PRC made limited (qualitative) use of results that may be questionable for other quality control reasons (such as poor sample spike recovery or lack of agreement between duplicate sample results). These results are useful in indicating the presence of a chemical in a particular sample. However, the results are not considered quantitatively accurate because of the quality control problems. PRC did not use such results when calculating potential exposures and risks associated with chemicals at Bowers Landfill.
- o PRC made full use of positive results below the CLP contract required detection limit (CRDL). CLP laboratories can quantify contaminant concentrations below the CRDL if the instrument detection limit for a particular analysis is less than the CRDL. However, according to CLP guidelines, these results must be reported as approximate or estimated. PRC considered these results both qualitatively useful in confirming the presence of a chemical and quantitatively useful as a measure of concentration. PRC used results below the CRDL when calculating potential exposures and risks. However, no exposure or risk estimates are based entirely on results below the CRDL.

1.3.2.1 Ground-Water Contamination

Dames & Moore collected two rounds of ground-water samples during the remedial investigation. Each of the 18 ground-water monitoring wells installed during the RI was sampled twice. Dames & Moore collected a third round of ground-water samples during the supplemental RI in March 1988. Samples were collected from 2 new wells and 3 of the original 18 wells. Figure 1-4 shows the locations of all wells sampled during the RI. Monitoring wells identified as W-*** are water table wells screened at the top of the upper aquifer. Wells identified as P-***A are screened at the bottom of the upper aquifer. Wells identified as P-***B are screened just above bedrock, at the base of the lower aquifer. (As noted in Chapter 2, the data collected to date are not sufficient to determine conclusively that the upper and lower aquifers are hydraulically separate.) Wells W-4 and P-4A are upgradient of the landfill and were installed as background wells. In addition to the monitoring wells, Dames & Moore collected one set of ground-water samples from four residential wells near Bowers Landfill.

Ground-water samples from rounds 1 and 2 were analyzed for the following parameters: volatile organic compounds (VOC); semivolatile organic compounds (SVOC); pesticides and polychlorinated biphenyls (PCB); inorganics (metals and

FIGURE 1-4 LOCATION OF WELLS SAMPLED



Source: Dames & Moore, 1988.

cyanide); and dioxin. Round 3 analyses included the same parameters, except pesticides, PCBs, and dioxin, which were not detected in any round 1 or round 2 samples. Complete results for all ground-water samples, including split samples collected by U.S. EPA, are included in Appendix A. A brief summary of the results follows.

Volatile Organic Compounds

Four VOCs were detected in ground-water samples collected during rounds 1 and 2 of the RI at Bowers Landfill. All four (benzene, acetone, methylene chloride, and tetrachloroethene) were found at concentrations above the CLP's CRDL and above background concentrations. Table 1-2 summarizes these results. Benzene and acetone were detected at low levels in well P-6B. This well is located approximately 100 feet west of the north-south leg of the landfill (see Figure 1-4) and is screened in the lower aquifer. Samples from rounds 1 and 2 contained acetone; benzene was detected only in first round samples. Acetone, methylene chloride, and tetrachloroethene were detected in second round samples from well W-12. This well is located upgradient of the landfill, on the eastern side of the east drainage ditch (see Figure 1-4). Well W-12 is screened at the top of the upper aquifer.

Round 3 samples were collected only from wells installed in the lower aquifer (P-5B, P-6B, P-8B, and two new wells, P-12B and P-13B). Only two VOCs, benzene and methylene chloride, were found in these samples, both at levels below the CRDL. Benzene was detected in well P-6B and methylene chloride was found in well P-13B.

Semivolatile Organic Compounds

Bis(2-ethylhexyl)phthalate was the only SVOC detected in ground water at concentrations above the CRDL. This compound was found at a concentration of 21 ppb in well P-7A during the first sampling round. It was also detected in eight other first round samples, in two second round samples, and in all five third round samples, at concentrations less than the CRDL. Three other SVOCs were found (each in a different well) at concentrations below the CRDL during first round samples. Results are summarized in Table 1-2.

TABLE 1-2
SUMMARY OF CONTAMINANTS DETECTED
IN VARIOUS ENVIRONMENTAL MEDIA AT BOWERS LANDFILL¹

Environmental Medium	Contaminant	Round 1		Round 2	
		Location ²	Concentration ³ (ppb)	Location ²	Concentration ³ (ppb)
<u>Ground Water</u>	<u>Volatile Organics</u>				
	Acetone	P-6B*	64	P-6B W-12	14 14
	Benzene	P-6B*	6		
	Methylene chloride			W-12d	7.4
	Tetrachloroethene			W-12	5.3
	<u>Semivolatile Organics</u>				
	Bis(2-ethylhexyl)phthalate	P-7A	21		
	<u>Inorganics</u>				
	Arsenic	RW-14 RW-15 RW-16	16 14 11		
	Barium	W-5 P-5A P-6B W-6* P-6B*	217 203 2,020 224 489	W-5 P-6B W-6 P-6B W-7 P-7A W-8 P-8A P-8B W-11 W-13d	213 2,020 734 531 383 306 308 308 684 351 305
	Copper	RW-17	32		
	Chromium	W-6* P-6B*	18 11		
	Lead			P-7A* W-12*	6.9 7.0
	Zinc	P-4Ab W-7 W-8 W-10 W-12	24 21 22 22 21	W-10	20
	Cyanide	W-4b	20		
<u>Surface Water</u>	<u>Volatile Organics</u>				
	Methylene chloride	SW-22 SW-23	5.2 5.7		

TABLE 1-2 (Continued)
SUMMARY OF CONTAMINANTS DETECTED
IN VARIOUS ENVIRONMENTAL MEDIA AT BOWERS LANDFILL¹

Environmental Medium	Contaminant	Round 1		Round 2	
		Location ²	Concentration ³ (ppb)	Location ²	Concentration ³ (ppb)
<u>Surface Water</u>	<u>Pesticides/PCBs</u>				
	Aroclor 1260	SW-18b	1.2		
		SW-21d	2.6		
	<u>Inorganics</u>				
	Aluminum	SW-22°	254	SW-25	263
		SW-23	117	SW-27	213
		SW-25	810	SW-29	1,140
	Barium	SW-23	50		
	Chromium	SW-22°	11		
	Lead			SW-29°	8.6
	Mercury	SW-22°	0.2	SW-26	0.27
	Zinc	SW-22°	32	SW-18b	27
		SW-28d	43	SW-19	33
				SW-20	30
				SW-21	23
				SW-22	28
				SW-23	37
				SW-29°	87
	Cyanide	SW-22°	13	SW-19	10
				SW-20	12
				SW-22	10
				SW-23	16
<u>Sediment</u>	<u>Volatile Organics</u>				
	Methylene chloride	SE-22°	43	SE-28	32
	Acetone	SE-22°	70		
	Toluene			SE-22	61
	<u>Semivolatile Organics</u>				
	4-Methylphenol	SE-25	660	SE-21	8,100
				SE-22	8,600
				SE-23	670
				SE-25	1,200
	Fluoranthene	SE-18b	700	SE-18b	900
		SE-22°	1,000	SE-25	950
	Pyrene	SE-18b	700	SE-18b	810
		SE-20	590	SE-25	800
		SE-22°	610		
	Benzo(a)anthracene	SE-19	3,600		

TABLE 1-2 (Continued)
SUMMARY OF CONTAMINANTS DETECTED
IN VARIOUS ENVIRONMENTAL MEDIA AT BOWERS LANDFILL¹

Environmental Medium	Contaminant	Round 1		Round 2	
		Location ²	Concentration ³ (ppb)	Location ²	Concentration ³ (ppb)
<u>Sediment</u>	<u>Semivolatile Organics</u>				
	Bis(2-ethylhexyl)phthalate	SE-19	840	SE-29*	1,090
		SE-20	1,100		
		SE-22*	840		
	Chrysene	SE-18b	550	SE-25	710
		SE-22*	480		
	Benzo(b)fluoranthene ⁴	SE-18b	910	SE-18b	890
		SE-19	750	SE-19	550
		SE-20	560	SE-22	730
				SE-25	1,000
				SE-28	760
	<u>Pesticides/PCBs</u>				
	Chlordane	SE-20	200		
		SE-21d	140		
		SE-22	170		
	Aroclor 1248	SE-27	2,300	SE-29*	550
		SE-28d	520		
		SE-29	1,600		
	<u>Inorganics⁵</u>		<u>(ppm)</u>		<u>(ppm)</u>
	Aluminum			SE-29*	16,400
	Barium	SE-22*	312		
	Cadmium	SE-20	1.7	SE-24	4.2
		SE-22*	5.6		
		SE-28d	1.8		
	Chromium	SE-21d	26		
	Cobalt			SE-29*	14
	Lead	SE-21	101	SE-26	79
		SE-27	104		
	Mercury			SE-21	1.1
				SE-26	1.4
				SE-29	1.0
	Vanadium			SE-29*	41
	Zinc	SE-21d	224		
		SE-22*	227		
		SE-28d	483		

TABLE 1-2 (Continued)
SUMMARY OF CONTAMINANTS DETECTED
IN VARIOUS ENVIRONMENTAL MEDIA AT BOWERS LANDFILL¹

Environmental Medium	Contaminant	Round 1		Round 2	
		Location ²	Concentration ³ (ppb)	Location ²	Concentration ³ (ppb)
<u>Soil</u> ⁶	<u>Semivolatile Organics</u>		(ppb)		
	Phenanthrene	SO-39	6,800		
		SO-44*	600		
	Fluoranthene	SO-39	9,100		
		SO-44	660		
	Pyrene	SO-39	11,000		
		SO-44	560		
	Benzo(a)anthracene	SO-39	4,300		
		SO-44*	530		
	Chrysene	SO-39	5,200		
		SO-44*	690		
	Benzo(b)fluoranthene ⁴	SO-11	460		
		SO-39	8,600		
		SO-42	470		
		SO-43	810		
		SO-44	960		
	Benzo(a)pyrene	SO-39	4,300		
		SO-44*	500		
	Indeno(1,2,3-cd)pyrene	SO-39	2,600		
	Benzo(g,h,i)perylene	SO-39	3,100		
		SO-44*	680		
	<u>Pesticides/PCBs</u>				
	Beta-BHC	SO-11	22		
	Dieldrin	SO-7	20		
		SO-11	27		
	Chlordane	SO-11	110		
		SO-35*	210		
		SO-44*	210		
	Aroclor 1242	SO-35*	600		
	Aroclor 1248	SO-31	1,200		
		SO-34	3,600		
		SO-35	350		
		SO-36	380		
		SO-37	350		
		SO-40	700		
		SO-41	1,100		
	Aroclor 1254	SO-33	300		
		SO-42	240		

TABLE 1-2 (Continued)
SUMMARY OF CONTAMINANTS DETECTED
IN VARIOUS ENVIRONMENTAL MEDIA AT BOWERS LANDFILL¹

Environmental Medium	Contaminant	Round 1		Round 2	
		Location ²	Concentration ³ (ppb)	Location ²	Concentration ³ (ppb)
Soil ⁶	Inorganics ⁵		(ppm)		
	Aluminum	SO-30	21,100		
		SO-36	21,700		
		SO-41	25,400		
	Arsenic	SO-11	169		
	Cobalt	SO-34	34		
	Lead	SO-35	179		
		SO-44	155		
	Vanadium	SO-30	57		
		SO-31	55		
		SO-33	51		
		SO-34	64		
		SO-35	54		
		SO-36	55		
		SO-40	52		
		SO-41	71		
	Zinc	SO-35*	540		

- Notes:
- ¹ This table summarizes results for some of the contaminants that were found in samples collected at Bowers Landfill. The table includes only contaminants that were detected at concentrations above the CRDL. In addition, results that were reported as approximate or estimated and results that may be suspect due to quality control/quality assurance (QA/QC) reasons are not included. Similarly, results for several metals that have minimal toxic effects (for example, calcium, iron, magnesium, or sodium) are also omitted. See Appendix A for a complete listing of all sampling results.
 - ² Sampling locations are coded with the following symbols:
 - a indicates a U.S. EPA split sample
 - b indicates a background sample
 - d indicates a duplicate sample
 When a contaminant was detected in more than one sample from a single location (for example, in a duplicate sample or a split sample), the highest result is reported.
 - ³ Blank entries in the table indicate that a contaminant was not found at concentrations above the CRDL during that sampling round.
 - ⁴ The CLP lab that analysed Dames & Moore samples stated that it could not distinguish between benzo(b)fluoranthene and benzo(k)fluoranthene. The reported concentration may be due to either or both of these contaminants.
 - ⁵ For inorganics in sediment and soil, this table reports only those values that were (1) above the CRDL and (2) at least twice the highest background concentration. This was done to better identify inorganics that might be present in elevated concentrations.
 - ⁶ Soil samples were collected only once; there are no round 2 data.

Pesticides/PCBs

No pesticides or PCBs were found in ground-water samples collected during sampling rounds 1 and 2.

Inorganics

Ground-water samples collected during sampling rounds 1 and 2 were analyzed for 24 inorganic parameters, including 23 metals and cyanide. Of the inorganics that are considered toxic, arsenic was found at concentrations above the CRDL in three residential well samples. However, none of the samples collected from monitoring wells during either sampling round contained arsenic at concentrations above the CRDL. Barium was found above the CRDL in 5 monitoring wells during round 1 and in 11 monitoring wells during round 2. Concentrations were highest in wells screened in the lower aquifer (P-5B, P-6B, and P-8B), with the highest concentration in well P-5B. This well is near the southern end of the landfill (see Figure 1-4). Chromium was found above the CRDL in two first-round samples and lead was found above the CRDL in two second-round samples. Cyanide was found above the CRDL in a single first round sample; however, this sample was collected from an upgradient (background) well, W-4. Inorganic results for rounds 1 and 2 are summarized in Table 1-2.

Round 3 samples were collected only from wells screened in the lower aquifer. Arsenic was detected in two wells (P-5B and P-8B), but at concentrations below the CRDL. Barium was found at concentrations above the CRDL in four of the five wells (P-5B, P-6B, P-8B, and P-13B). Barium concentrations for wells P-5B, P-6B, and P-8B were very similar to concentrations found in rounds 1 and 2 samples. However, the new lower aquifer wells (P-12B and P-13B) had lower barium concentrations.

Several metals were found in nearly all ground-water samples. These include calcium, iron, magnesium, manganese, and sodium. These metals are relatively non-toxic (some are essential nutrients), and their presence at the levels found in ground water is due to their natural occurrence in subsurface soils and rocks near Bowers Landfill. Complete sampling results for all inorganics are included in Appendix A.

Dioxin

Dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin) was not detected in any ground-water samples collected at Bowers Landfill.

1.3.2.2 Surface Water Contamination

Dames & Moore collected surface water samples from 12 locations near Bowers Landfill during the RI. Of the 12 locations, 5 are along the Scioto River, 5 are along the drainage ditch or quarries east of the landfill, 1 is from the drainage ditch west of the landfill, and 1 is from a drainage area at the southern end of the landfill. Sampling location SW-18 on the Scioto River is upstream of Bowers Landfill and is considered a background sampling location. Surface water sampling locations are shown in Figure 1-5. During the RI, Dames & Moore sampled each location twice. All samples were analyzed for VOCs, SVOCs, pesticides/PCBs, inorganics, and dioxin. The following sections briefly summarize surface water sample results. Appendix A contains complete results for all surface water samples, including U.S. EPA split samples.

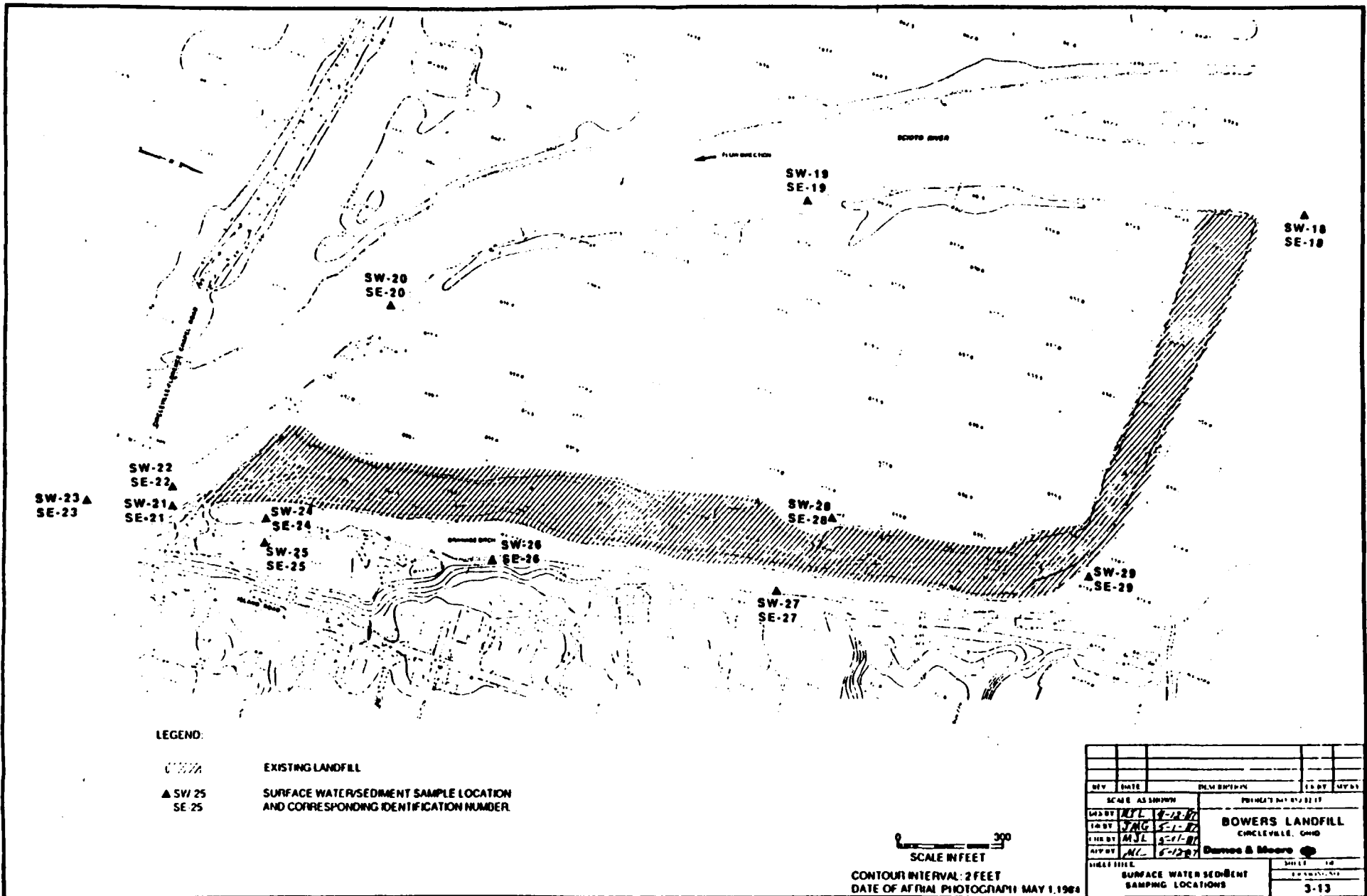
Volatile Organic Compounds

Only three VOCs were detected in surface water samples during the RI. These compounds are methylene chloride, tetrachloroethene, and 1,2-dichloroethane. Of the three VOCs, only methylene chloride was found at concentrations above the CRDL -- at locations SW-22 and SW-23 during the first sampling round. These sampling locations are along the Scioto River, approximately 100 and 300 feet downstream of the landfill, respectively.

Semivolatile Organic Compounds

All surface water samples were analyzed for 65 SVOCs. However, only one SVOC, diethylphthalate, was detected. This compound was found at location SW-22 during round 1 at a concentration below the CRDL.

FIGURE 1-5 SURFACE WATER AND SEDIMENT SAMPLING LOCATIONS



Pesticides/PCBs

Aroclor 1260, a PCB compound, was detected in two surface water samples from round 1. This PCB compound was found in a duplicate sample (but not in the original sample) from location SW-21, a drainage area near the southern end of Bowers Landfill. Aroclor 1260 was also found in the background sample from SW-18, upstream of the site. Results are shown in Table 1-2. No pesticides were found in surface water samples.

Inorganics

Surface water samples collected during both sampling rounds were analyzed for 23 metals and cyanide. Several inorganics that are considered toxic were found at concentrations above the CRDL in these samples. These include aluminum, barium, chromium, lead, mercury, zinc, and cyanide; results are included in Table 1-2. Most of these inorganics were found at only one or two sampling locations in each round. The results do not exhibit any distinct pattern with regard to sampling location. However, during round 1, most of the inorganics above the CRDL were found at sampling locations SW-22 and SW-23. These locations are along the Scioto River, approximately 100 and 300 feet downstream of the southern end of Bowers Landfill.

Several metals were found in nearly all surface water samples. These include calcium, iron, magnesium, manganese, and sodium. As stated earlier, these metals are relatively non-toxic (some are essential nutrients), and presence at the levels found in surface water is due to their natural occurrence in soils and rocks near Bowers Landfill. Complete sampling results for all inorganics are included in Appendix A.

Dioxin

Dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin) was not detected in any surface water samples collected at Bowers Landfill.

1.3.2.3 Sediment Contamination

Dames & Moore collected sediment samples from 12 locations near Bowers Landfill during the RI. These locations were the same as the surface water locations (that is, at each surface water sampling location, Dames & Moore also collected a sediment sample) and are shown in Figure 1-5. Sampling location SW-18 on the Scioto River is upstream of Bowers Landfill and is considered a background sampling location.

During the RI, Dames & Moore sampled each location twice. All samples were analyzed for VOCs, SVOCs, pesticides/PCBs, inorganics, and dioxin. The following sections briefly summarize sediment sample results. Appendix A contains complete results for all sediment samples, including U.S. EPA split samples.

Volatile Organic Compounds

Of the four VOCs found in sediment samples collected during the RI, three were found at concentrations above the CRDL: methylene chloride, acetone, and toluene. Of the three, only methylene chloride was found during both sampling rounds. This compound was found in the round 1 sample from location SE-22, along the Scioto River near the southern end of the landfill. In round 2, methylene chloride was detected at location SE-28, in the drainage ditch west of the landfill. The other two VOCs, acetone and toluene, were both found at SE-22 in rounds 1 and 2, respectively. These results are shown in Table 1-2.

Semivolatile Organic Compounds

Seven SVOCs were found in sediment samples at concentrations above the CRDL. However, Table 1-2 shows that for four of these SVOCs (fluoranthene, pyrene, chrysene, and benzo(b)fluoranthene), background concentrations from location SE-18 were similar to concentrations found near the landfill. One SVOC, benzo(a)anthracene, was found at a single location (SE-19) during round 1. The remaining two SVOCs, 4-methylphenol and bis(2-ethylhexyl)phthalate, were found in both sampling rounds and at several locations. The occurrence of 4-methylphenol appears to be concentrated near the southern end of the landfill, at locations SE-

21, SE-22, SE-23, and SE-25. Bis(2-ethylhexyl)phthalate did not exhibit any pattern of distribution, and was found at four widely separated locations.

Pesticides/PCBs

The pesticide chlordane was found at three sampling locations during round 1. All three locations (SE-20, SE-21, and SE-22) are on or near the Scioto River at the southern end of Bowers Landfill (see Figure 1-5). Chlordane was also found in a duplicate sample from SE-22, but not in the U.S. EPA split sample collected at this location. Round 2 samples from these locations did not contain chlordane.

One PCB compound, Aroclor 1248, was also found in sediment samples; results are included in Table 1-2. Aroclor 1248 was found in round 1 samples collected near the northeast corner of Bowers Landfill. (Aroclor 1248 was also found in several soil samples from this area of the landfill; see Section 1.3.2.4). All of these sediment samples were collected from drainage ditches east (SE-27, SE-29) and west (SE-28) of the landfill (see Figure 1-5). Dames & Moore's round 2 samples from these locations did not contain PCBs; however, Aroclor 1248 was found in U.S. EPA's split sample from SE-29 in round 2.

Inorganics

Most of the inorganics analyzed for by CLP labs were found in most of the sediment samples collected at Bowers Landfill. This was expected, since many of these metals occur naturally in soil and rocks. PRC attempted to focus on those inorganics that might be associated with landfilling activities. To do this, we looked at inorganics that (1) are considered toxic, (2) were present at concentrations above the CRDL, and (3) were present at concentrations significantly higher than background. Table 1-2 lists those inorganics that were both above the CRDL and twice the background concentration (from sample location SE-18).

The inorganics in Table 1-2 include aluminum, barium, cadmium, chromium, cobalt, lead, mercury, vanadium, and zinc. Most of these were found at only a few (no more than four) sampling locations. Furthermore, the results do not exhibit any consistent pattern from round 1 to round 2, or with regard to sampling locations.

Dioxin

Dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin) was not detected in any sediment samples collected at Bowers Landfill.

1.3.2.4 Soil Contamination

Dames & Moore collected a single round of soil samples during the RI. Fifteen surficial soil samples were collected on or near the landfill (sampling locations SO-30 through SO-44). In addition, Dames & Moore collected Shelby tube samples at seven locations. (For each Shelby tube, the portion of the tube from ground surface to a depth of 6 inches was analyzed; thus, these samples are similar to the surficial soil samples.) Five of the Shelby tube samples were collected at monitoring well locations. The remaining two were collected on the west side of the Scioto River, upstream of Bowers Landfill (locations SO-45 and SO-46). These samples were collected as background samples. Dames & Moore collected a second round of surficial soil samples during the supplemental RI. Three locations from round 1 were resampled: SO-11, SO-34, and SO-36. In addition, Dames & Moore sampled two new locations on the landfill, three new locations west of the Scioto River, and two locations in the agricultural field north of the landfill. Figure 1-6 shows all soil sampling locations.

All soil samples from round 1 were analyzed for VOCs, SVOCs, pesticides/PCBs, inorganics, and dioxin. Table 1-2 summarizes the analytical parameters that were detected at concentrations above the CRDL. Round 2 soil samples were analyzed only for arsenic and lead. Complete soil sample results appear in Appendix A.

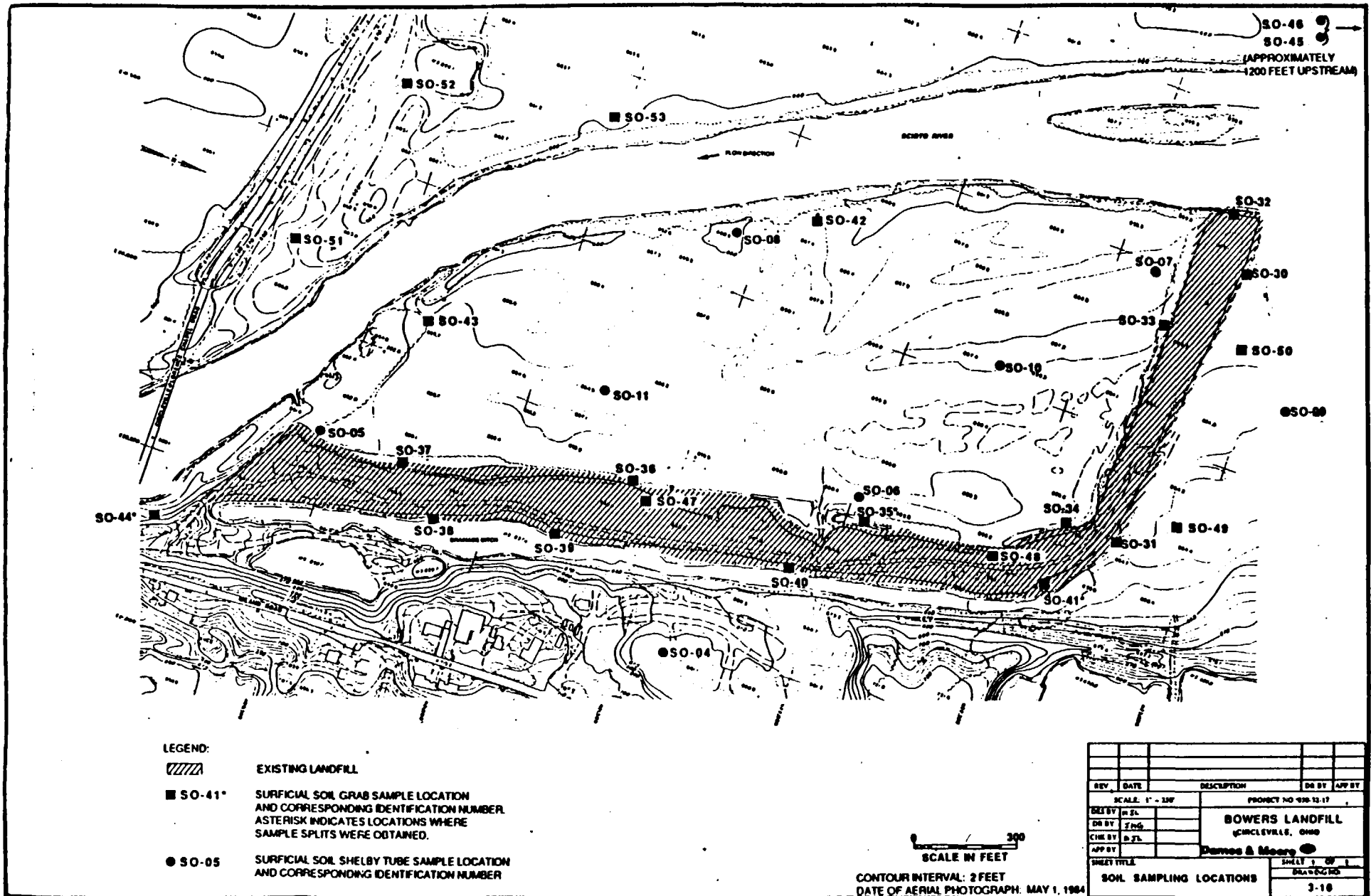
Volatile Organic Compounds

None of the soil samples contained VOCs at concentrations above the CRDL.

Semivolatile Organic Compounds

Nine SVOCs were found at concentrations above the CRDL in soil samples collected at Bowers Landfill. All nine were also found in background soil samples,

FIGURE 1-6 SOIL SAMPLING LOCATIONS



Source: Dames & Moore, 1988.

but at concentrations below the CRDL. The SVOCs belong to a class of compounds called polynuclear (or polycyclic) aromatic hydrocarbons (PAHs). These compounds are often formed as products of incomplete combustion. Their presence at Bowers Landfill might be due to previous burning activities that were described in Section 1.1.3. However, since PAHs were also found in background samples, some portion of the concentrations found in samples from the landfill could be attributed to external sources.

The highest SVOC concentrations occurred at sampling location SO-39. This location is halfway up the north-south leg of the landfill, on the east side. All nine SVOCs were found at SO-39. Location SO-44 also showed high levels of SVOC contamination, although concentrations were approximately one order of magnitude lower than at SO-39. This location is at the southern end of the landfill. One SVOC (benzo(b)fluoranthene) was found at concentrations above the CRDL at locations SO-11, SO-42, and SO-43. All three locations are in the field west of the landfill.

Pesticides/PCBs

Three pesticides were detected in soil samples -- beta-BHC, dieldrin, and chlordane. The pesticides were found at two locations in the field west of the landfill (SO-7 and SO-11), one location at the western edge of the landfill (SO-35), and one location south of the landfill (SO-44). One of the pesticides, chlordane, was also found in round 1 sediment samples. The presence of these pesticides in the field west of the landfill could be associated with agricultural activities that have occurred in this field.

Three PCB compounds were detected in soil samples. These include Aroclor 1242, Aroclor 1248, and Aroclor 1254. PCBs were found at nine locations. Eight of the nine locations are on or adjacent to the landfill. The ninth location, SO-42, is in the field west of the landfill, near the Scioto River. Six of the nine locations are clustered near the northeast corner of the landfill. Aroclor 1248 was the predominant PCB mixture found at these locations. Aroclor 1248 was also found at similar concentrations in sediment samples collected from this area of the landfill. Thus, the presence of PCBs in soil samples appears to be related to landfilling activities.

Inorganics

Most of the inorganics analyzed for by CLP labs were found in most of the soil samples collected at Bowers Landfill. This was expected, since many of these metals occur naturally in soil and rocks. PRC attempted to focus on those inorganics that might be associated with landfilling activities. To do this, we looked at inorganics that (1) are considered toxic, (2) were present at concentrations above the CRDL, and (3) were present at concentrations significantly higher than background. Table 1-2 lists those inorganics from round 1 samples that were both above the CRDL and twice the background concentration (from sampling locations SO-45 and SO-46).

The inorganics in Table 1-2 include aluminum, arsenic, cobalt, lead, vanadium, and zinc. With the exception of vanadium, which was elevated at eight sampling locations, elevated levels of inorganics were found at only a few (no more than three) sampling locations. Most of the sampling locations with elevated inorganic concentrations were on or adjacent to the landfill.

Round 2 soil samples were analyzed for arsenic and lead only. Arsenic concentrations were similar for samples collected on the landfill, in adjacent agricultural fields, and west of the Scioto River. Lead concentrations for these three areas were also similar, with one exception. The lead concentration in one sample from location SO-47 was more than three times greater than background levels. However, Dames & Moore collected triplicate samples from this location on the landfill. The remaining two samples from SO-47 had lead concentrations near background levels.

Dioxin

Dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin) was not detected in any soil samples collected at Bowers Landfill.

1.4 SELECTION OF INDICATOR CHEMICALS

As discussed above, a number of inorganic and organic chemicals were identified in environmental media in and surrounding the Bowers Landfill site. These media are surface water, ground water, soils, and sediment. Ideally, this endangerment assessment would present the individual and cumulative risks to human health and the environment from exposure to all the contaminants identified in each medium at or near the site. However, such an effort would be impractical due to extreme time and resource requirements. PRC instead focused this endangerment assessment on a set of "indicator chemicals" that may pose the greatest potential risk to human health and the environment at the site, in accordance with U.S. EPA guidance (Superfund Public Health Evaluation Manual (SPHEM), U.S. EPA, 1986a). The procedures used to select these chemicals, as well as a list of the indicator chemicals, are presented below.

1.4.1 Procedures

PRC followed the guidance referenced above in selecting indicator chemicals. The procedures in SPHEM call for calculating indicator scores (IS) based on the mean and maximum concentrations of each contaminant in each environmental medium. However, PRC chose to focus on those chemicals likely to pose the greatest risk. Therefore, with U.S. EPA concurrence, PRC used only the maximum values for each chemical in calculating the IS. The IS process is designed for sites where a relatively large number of chemicals has been detected and where simultaneous consideration of all physical, chemical, and concentration information is too cumbersome. The purpose of the process is to identify a set of indicator chemicals likely to pose the greatest risks. However, it must be emphasized that the IS process is a selection process -- it is not designed to evaluate risks associated with selected chemicals. Risks are evaluated later in the endangerment assessment, only after the fate and transport, exposure potential, and toxicity of the indicator chemicals have been determined.

To calculate indicator scores, maximum concentrations for each chemical were multiplied by toxicity constants (U.S. EPA, 1986a) specific for the chemical, environmental medium (water, soil, or sediment), and health effects (carcinogenic

and noncarcinogenic). Equation 1-1 is an example of such a calculation for a hypothetical chemical A in ground water.

$$\begin{array}{lclcl} \text{Ground-Water Concentration} & & \text{Toxicity Constant} & & \text{Ground-Water} \\ \text{of Chemical A} & \times & \text{for Chemical A} & = & \text{IS} & (1-1) \\ & & \text{in water based on} & & \text{for Chemical A} \\ & & \text{potential carcino-} & & \text{based on potential} \\ & & \text{genicity} & & \text{carcinogenicity} \end{array}$$

When toxicity constants based on carcinogenic as well as noncarcinogenic health effects were available for a specific chemical, two sets of calculations were made. Table 1-3 presents these calculations. It also identifies the frequency at which these chemicals were detected and the maximum concentrations found. U.S. EPA (1986a) has not developed toxicity constants for several of the chemicals found at or near Bowers Landfill. These chemicals are listed in Table 1-3; however, IS cannot be calculated.

The chemicals were then ranked by the magnitude of their IS for each environmental medium. Potential carcinogens were ranked separately from noncarcinogens. Table 1-4 presents the highest ranking carcinogens and noncarcinogens based on maximum concentrations. It also identifies the number of times the chemical was identified above the CRDL and the ratio of the maximum concentration to the maximum background concentration.

The final step in selecting indicator chemicals involves applying nonquantitative factors to the indicator scores. PRC followed the procedures outlined in Section 3.2 of SPHEM and considered the following factors:

- o The mobility and persistence of the chemicals in the environment, including water solubility, vapor pressure, Henry's Law constant, and organic carbon partition coefficient
- o A chemical's toxicity in environmental media of concern, and weight of evidence for carcinogenicity
- o Frequency of detection
- o Spatial distribution of the contaminants (on-site/off-site and within specific environmental media)
- o A chemical's representativeness of a class of compounds found at the site

TABLE 1-3a
INDICATOR SCORES -- GROUND WATER
BOWERS LANDFILL

COMPOUND	Frequency of Detection, <u>(a/b/c)</u>	Maximum Concentration ² <u>(ug/L)</u>	<u>Carcinogens</u>		<u>Noncarcinogens</u>	
			Toxicity Constant ³ <u>Water (L/mg)</u>	Indicator <u>Score</u>	Toxicity Constant ³ <u>Water (L/mg)</u>	Indicator <u>Score</u>
o <u>VOLATILE ORGANICS</u>						
Methylene chloride	7/1/41	7.4			9.20 E-04	6.81 E-06
Acetone	5/3/41	64				
Benzene	2/1/41	6	7.71 E-03	4.63 E-05	1.17 E-01	7.02 E-04
Tetrachloroethene	2/1/41	5.3	8.86 E-03	4.70 E-05	9.62 E-03	5.10 E-05
o <u>SEMIVOLATILES</u>						
Bis(2-ethylhexyl)phthalate	15/1/41	21	5.71 E-04	1.20 E-05		
2-Methylnaphthalene	1/0/41	2.8 J				
Di-n-butylphthalate	1/0/41	2.6 J			3.81 E-02	9.91 E-05
N-nitrosodiphenylamine	1/0/41	4.3 J				
o <u>INORGANICS</u>						
Aluminum	9/0/41	[163]				
Arsenic	28/6/41	16	4.07 E+00	6.51 E-02	1.80 E+01	2.90 E-01
Barium	41/27/41	2070			4.08 E+00	8.45 E+00
Cobalt	6/0/41	[4.2]				
Copper	15/1/41	32			7.14 E-01	2.28 E-02
Lead	9/5/41	7.0			8.93 E-01	6.25 E-03
Nickel	1/0/41	[28]				
Selenium	4/1/41	[3.5]			1.05 E+02	3.68 E-01
Vanadium	5/0/41	[10]			1.43 E-01	1.43 E-03
Zinc	41/8/41	174 E			1.07 E-01	1.86 E-02

Notes are listed at end of table

TABLE 1-3b
INDICATOR SCORES -- SURFACE WATER
BOWERS LANDFILL

COMPOUND	Frequency of Detection, <u>(a/b/c)</u>	Maximum Concentration ² <u>(ug/L)</u>	Carcinogens		Noncarcinogens	
			Toxicity Constant ³ <u>Water (L/mg)</u>	Indicator <u>Score</u>	Toxicity Constant ³ <u>Water (L/mg)</u>	Indicator <u>Score</u>
o <u>VOLATILE ORGANICS</u>						
1,2-Dichloroethane	2/0/22	3.1 J	5.86 E-02	1.02 E-04	1.76 E-02	5.46 E-05
Tetrachloroethene	2/0/22	1.1 J	8.86 E-03	9.75 E-06	9.62 E-03	1.06 E-05
Methylene chloride	4/2/22	5.7			9.20 E-04	5.24 E-06
o <u>SEMIVOLATILES</u>						
Diethylphthalate	1/0/22	3.0 J			2.67 E-04	8.01 E-07
o <u>PESTICIDES/PCBS</u>						
Aroclor 1260	1/1/22	2.6	5.71 E-01	1.48 E-03		
o <u>INORGANICS</u>						
Aluminum	21/6/22	1580 E				
Arsenic	6/0/22	[4.6]	4.07 ⁴ E+00	1.87 E-02	1.80 E+01	8.28 E-02
Barium	22/1/22	[199]			4.08 E+00	8.12 E-01
Chromium	2/1/22	11				
Cobalt	1/0/22	[3.8]				
Copper	4/0/22	[9.2]			7.14 E-01	6.57 E-03
Lead	7/4/22	8.6 S			8.93 E-01	7.68 E-03
Mercury	2/2/22	0.27			1.84 E+01	4.97 E-03
Silver	2/1/22	4.0			2.00 E+01	8.00 E-02
Thallium	1/0/22	[2.6] N				
Vanadium	2/0/22	[4.2]			1.43 E-01	6.01 E-04
Zinc	22/14/22	87			1.07 E-01	9.31 E-03
Cyanide	5/5/22	16				

Notes are listed at end of table

TABLE 1-3c
INDICATOR SCORES -- SOILS
BOWERS LANDFILL

COMPOUND	Frequency of Detection ¹ (a/b/c)	Maximum Concentration ² (ug/kg)	Carcinogens		Noncarcinogens	
			Toxicity Constant ³ Soil (kg/mg)	Indicator Score	Toxicity Constant ³ Soil (kg/mg)	Indicator Score
o <u>VOLATILE ORGANICS</u>						
Bromomethane	1/0/20	2.3 J				
o <u>SEMIVOLATILES</u>						
Benzoic acid	3/0/20	360 J				
Naphthalene	2/0/20	18 J				
2-Methylnaphthalene	2/0/20	11 J				
Acenaphthylene	1/0/20	190 J				
Acenaphthene	2/0/20	280 J				
Dibenzofuran	3/0/20	270 J				
Fluorene	2/0/20	710 J				
Phenanthrene	17/2/20	6800				
Anthracene	2/0/20	980 J				
Di-n-butylphthalate	5/0/20	180 J			1.90 E-06	3.42 E-07
Fluoranthene	20/2/20	9100				
Pyrene	20/2/20	11000				
Butylbenzylphthalate	1/0/20	79 J				
Benzo(a)anthracene	18/2/20	4300	2.91 E-05	1.25 E-04		
Bis(2-ethylhexyl)phthalate	15/0/20	420 J	2.86 E-08	1.20 E-08		
Chrysene	19/2/20	5200				
Di-n-octyl phthalate	2/0/20	130 J				
Benzo(b)fluoranthene	18/5/20	8600				
Benzo(k)fluoranthene	18/5/20	8600				
Benzo(a)pyrene	16/2/20	4300	2.28 E-04	9.80 E-04	1.33 E-03	5.72 E-03
Indeno(1,2,3-c,d)pyrene	14/1/20	2600				
Dibenz(a,h)anthracene	1/0/20	960 J	5.04 E-04	4.84 E-04		
Benzo(g,h,i)perylene	14/2/20	3100				

Notes are listed at end of table

TABLE 1-3c
INDICATOR SCORES -- SOIL (Continued)
BOMERS LANDFILL

COMPOUND	Frequency of Detection ¹ (a/b/c)	Maximum Concentration ² (ug/kg)	Carcinogens		Noncarcinogens		
			Toxicity Constant ³ Soil (kg/mg)	Indicator Score	Toxicity Constant ³ Soil (kg/mg)	Indicator Score	
o <u>PESTICIDES/PCBS</u>							
Beta-BHC	1/1/20	22	2.49 E-06	5.48 E-08			
Dieldrin	2/2/20	27	1.83 E-04	4.94 E-06			
Chlordane	3/3/20	210	2.16 E-05	4.54 E-06			
Aroclor 1242	1/1/20	600	2.86 E-05	1.72 E-05			
Aroclor 1248	7/7/20	3600	2.86 E-05	1.03 E-04			
Aroclor 1254	2/2/20	300	2.86 E-05	8.58 E-06			
o <u>INORGANICS</u>							
		(mg/kg)					
Aluminum	20/20/20	25400					
Arsenic	27/27/27	169 S	2.03 E-04	3.43 E-02	9.00 E-04	1.52 E-01	
Barium	20/20/20	287			2.04 E-04	5.85 E-02	
Beryllium	20/5/20	1.2					
Cadmium	19/18/20	2.7			2.23 E-04	6.02 E-04	
Chromium	20/20/20	28					
Cobalt	20/18/20	34					
Copper	20/20/20	55			3.57 E-05	1.96 E-03	
Lead	27/27/27	179			4.46 E-05	7.98 E-03	
Mercury	20/20/20	0.58			9.21 E-04	5.34 E-04	
Nickel	20/20/20	43			2.13 E-04	9.16 E-03	
Selenium	2/0/20	[0.56] M			5.26 E-03	2.94 E-03	
Silver	1/1/20	0.47 M			1.00 E-03	4.70 E-04	
Thallium	8/1/20	0.49					
Vanadium	20/20/20	71			7.14 E-06	5.07 E-04	
Zinc	20/20/20	540			5.33 E-06	2.88 E-03	

Notes are listed at end of table

TABLE 1-3d
INDICATOR SCORES -- SEDIMENT
BOMERS LANDFILL

COMPOUND	Frequency of Detection ¹ (a/b/c)	Maximum Concentration ² (ug/kg)	Carcinogens		Noncarcinogens	
			Toxicity Constant ³ Soil (kg/mg)	Indicator Score	Toxicity Constant ³ Soil (kg/mg)	Indicator Score
o <u>VOLATILE ORGANICS</u>						
Methylene chloride	2/2/22	43			4.52 E-06	1.94 E-07
Acetone	2/1/22	70				
Chloroform	2/0/22	7.1 J	2.81 E-06	2.00 E-08		
Toluene	2/1/22	61			2.60 E-07	1.59 E-08
o <u>SEMIVOLATILES</u>						
Benzoic acid	3/0/22	1100 J				
Acenaphthylene	1/0/22	63 J				
Phenanthrene	17/0/22	550 J				
Anthracene	4/0/22	76 J				
Di-n-butylphthalate	2/0/22	127 J			1.90 E-06	2.41 E-07
Fluoranthene	20/2/22	1000				
Pyrene	20/3/22	800				
Butylbenzylphthalate	2/0/22	79 J				
Benzo(a)anthracene	15/1/22	3600	2.91 E-05	1.05 E-04		
Bis(2-ethylhexyl)phthalate	13/4/22	1100	2.86 E-08	3.15 E-08		
Chrysene	17/2/22	710				
Di-n-octyl phthalate	6/0/22	190 J				
Benzo(b)fluoranthene	18/6/22	1000				
Benzo(a)pyrene	16/0/22	400 J	2.28 E-04	9.12 E-05	1.33 E-03	5.32 E-04
Indeno(1,2,3-c,d)pyrene	11/0/22	270 J				
Dibenz(a,h)anthracene	2/0/22	130 J	5.04 E-04	6.55 E-05		
Benzo(g,h,i)perylene	10/0/22	290 J				
4-Methylphenol	8/5/22	8600				
Phenol	4/0/22	540 J			5.02 E-06	2.71 E-06

Notes are listed at end of table

TABLE 1-3d
INDICATOR SCORE -- SEDIMENT (Continued)
BOWERS LANDFILL

COMPOUND	Frequency of Detection ¹ (a/b/c)	Maximum Concentration ² (ug/kg)	Carcinogens		Noncarcinogens	
			Toxicity Constant ³ Soil (kg/mg)	Indicator Score	Toxicity Constant ³ Soil (kg/mg)	Indicator Score
o <u>PESTICIDES/PCBS</u>						
Chlordane	3/3/22	200	2.16 E-05	4.32 E-06		
Aroclor 1248	4/4/22	2300	2.86 E-05	6.58 E-05		
o <u>INORGANICS</u>		(mg/kg)				
Aluminum	22/22/22	16400				
Arsenic	22/20/22	57	2.03 E-04	1.16 E-02	9.00 E-04	5.13 E-02
Barium	22/20/22	312			2.04 E-04	6.36 E-02
Beryllium	9/0/22	(0.90)				
Cadmium	10/8/22	5.6			2.23 E-04	1.25 E-03
Chromium	22/21/22	26				
Cobalt	20/2/22	14				
Copper	22/22/22	30			3.57 E-05	1.07 E-03
Lead	22/22/22	104			4.46 E-05	4.64 E-03
Mercury	14/14/22	1.4			9.21 E-04	1.29 E-03
Nickel	21/21/22	48			2.13 E-04	1.02 E-02
Silver	8/1/22	8.0			1.00 E-03	8.00 E-03
Thallium	4/0/22	(0.93)				
Vanadium	22/9/41	41			7.14 E-06	2.93 E-04
Zinc	22/22/22	483			5.33 E-06	2.57 E-03

Notes are listed at end of table

TABLE 1-3
INDICATOR SCORE
BOWERS LANDFILL

NOTES:

- 1 Frequency of detection = $a/b/c$, where

a = number of times detected
b = number of times above CRDL
c = total number of samples

Totals include samples where results are questionable due to quality assurance/quality control problems; for example, results qualified as * and N are included in totals (see note 2 below); background samples are not included in total

- 2 J Indicates an estimated value; compound was found at concentrations below the CRDL

[xx] See note for J

E Indicates that the concentration was estimated due to presence of interference during analysis

* Indicates that result may be questionable because laboratory duplicate analysis was not within CLP control limits

S Indicates value determined by Method of Standard Additions

N Indicates spike sample recovery is not within control limits

- 3 Where no constant is reported, value was not available

- 4 The CLP lab that analyzed the Dames & Moore samples could not distinguish between benzo(b)fluoranthene and benzo(k)fluoranthene. The reported concentration may be due to either or both of these contaminants
-

TABLE 1-4
HAZARD RANKINGS -- SUMMARY

CARCINOGENIC CHEMICALS			
(Rank) Compound	Maximum Concentration (ug/L)	# Times Above CRDL	Maximum Concentration/ Maximum Background Concentration ²

I. SURFACE WATER (22 samples)

(1) Arsenic	[4.6]	0	--
(2) Aroclor 1260	2.6	1	2.17
(3) 1,2-Dichloroethane	3.1 J	0	--
(4) Tetrachloroethene	1.1 J	0	1.00

II. GROUND WATER (41 samples)

(1) Arsenic	16	6	2.05
(2) Benzene	6	1	--
(3) Bis(2-Ethylhexyl)Phthalate	24	1	4.77
(4) Tetrachloroethene	5.3	1	--

NONCARCINOGENIC CHEMICALS			
(Rank) Compound	Maximum Concentration (ug/L)	# Times Above CRDL	Maximum Concentration/ Maximum Background Concentration ²

(1) Barium	[199]	1	3.32
(2) Arsenic	[4.6]	0	--
(3) Silver	4.0	1	--
(4) Zinc	87	14	2.56
(5) Lead	8.65	4	1.30
(6) Copper	[9.2]	0	--
(7) Mercury	0.27	2	--
(8) Vanadium	[4.2]	0	--
(9) 1,2-Dichloroethane	3.1 J	0	--
(10) Tetrachloroethene	1.1 J	0	1.00
(11) Methylene chloride	5.7	2	2.04
(12) Diethylphthalate	3.0 J	0	--

(1) Barium	2070	27	13.44
(2) Selenium	[3.5]	1	--
(3) Arsenic	16	6	2.05
(4) Copper	32	1	2.91
(5) Zinc	174 E	8	7.25
(6) Lead	7.0	5	--
(7) Vanadium	[10]	0	--
(8) Benzene	6	1	--
(9) Di-n-butylphthalate	2.6 J	0	--
(10) Tetrachloroethene	5.3	1	--
(11) Methylene Chloride	7.4	1	2.47

TABLE 1-4 (Continued)
HAZARD RANKINGS -- SUMMARY

CARCINOGENIC CHEMICALS				
(Rank) Compound	Maximum Concentration (ug/kg)	# Times Above CRDL	Maximum Concentration/ Maximum Background Concentration ²	

III. SOIL (20 samples)

(1) Arsenic ³	169000	S	27	15.36
(2) Benzo(a)pyrene	430		2	28.67
(3) Dibenzo(a,h)anthracene	960	J	0	--
(4) Benzo(a)anthracene	4300		2	30.71
(5) Aroclor 1248	3600		7	--
(6) Aroclor 1242	600		1	--
(7) Aroclor 1254	300		2	--
(8) Dieldrin	27		2	--
(9) Chlordane	210		3	--
(10) Beta-BHC	22		1	--
(11) Bis(2ethylhexyl)phthalate	420	J	0	3.82

IV. SEDIMENT (22 samples)

(1) Arsenic	57000	*	20	4.75
(2) Benzo(a)anthracene	3600		1	8.57
(3) Benzo(a)pyrene	400	J	0	0.89
(4) Aroclor 1248	2300		4	--
(5) Dibenzo(a,h)anthracene	130	J	0	0.81
(6) Chlordane	200		3	--
(7) Bis(2-ethylhexyl)phthalate	1100		2	--
(8) Chloroform	7.1	J	0	1.27

NONCARCINOGENIC CHEMICALS				
(Rank) Compound	Maximum Concentration (ug/kg)	# Times Above CRDL	Maximum Concentration/ Maximum Background Concentration ²	

(1) Arsenic ³	169000	S	27	15.36
(2) Barium	287000		20	1.84
(3) Nickel	43000		20	1.26
(4) Lead	179000		27	2.42
(5) Benzo(a)pyrene	4300		2	28.67
(6) Selenium	[560]	N	0	--
(7) Zinc	540000		20	2.45
(8) Copper	55000		20	1.62
(9) Cadmium	2700		18	1.28
(10) Mercury	580		20	1.81
(11) Vanadium	71000		20	3.09
(12) Silver	470	N	1	--
(13) Di-n-butylphthalate	180	J	0	--

(1) Barium	312000		20	2.64
(2) Arsenic	57000	*	20	2.64
(3) Nickel	48000		21	1.55
(4) Silver	8000		1	1.90
(5) Lead	104000		22	2.74
(6) Zinc	483000		22	5.08
(7) Mercury	1400		14	3.50
(8) Cadmium	5600		7	2.67
(9) Copper	30000		22	1.36
(10) Benzo(a)pyrene	400	J	0	0.89
(11) Vanadium	41000		8	3.42
(12) Phenol	540	J	0	--
(13) Di-n-butylphthalate	120	J	0	--
(14) Methylene chloride	43		1	--
(15) Toluene	61		1	--

TABLE 1-4 (Continued)
HAZARD RANKINGS -- SUMMARY

Notes:

1 Total includes samples where chemical was found at concentrations above the CRDL, but results were questionable due to quality control/quality assurance problems; total does not include background samples

2 Background concentrations were obtained from the following sample locations:

Surface Water:	SW-18
Ground Water:	Wells W-4 and P-4A
Soil:	SO-45 and SO-46
Sediment:	SE-18

3 Arsenic and lead were analyzed in 27 non-background soil samples.

J Indicates an estimated value; compound was found at concentrations below the CRDL

[XX] See note for J

E Indicates that concentration was estimated due to presence of interference during analysis

* Indicates that result may be questionable because laboratory duplicate analysis was not within CLP control limits

-- Chemical was not detected in background samples; ratio cannot be calculated

S Indicates value determined by Method of Standard Additions

1.4.2 Indicator Chemicals

After reviewing the relative rankings and considering the nonqualitative factors noted in Section 1.4.1, PRC selected, with U.S. EPA concurrence, the following indicator chemicals to evaluate the risk posed by Bowers Landfill.

Inorganic Chemicals

Barium
Lead
Mercury

Organic Chemicals

Benzene
Chlordane
4-Methylphenol
Polychlorinated biphenyls (PCB)
Polynuclear aromatic hydrocarbons (PAH)
Tetrachloroethene

A brief rationale for each chemical selected is given below.

1.4.2.1 Inorganic Indicator Chemicals

Of the inorganic indicator chemicals identified, barium was chosen because it was found in all environmental media sampled, it was present at concentrations greater than twice the background concentrations, and it ranked high among the noncarcinogenic compounds in each medium. Lead was chosen because it was found in all media sampled, it was present at concentrations greater than twice the background concentrations, and it is toxic to humans through soil ingestion (children have been known to consume foreign objects including soils, a phenomenon known as pica). Mercury was included as an indicator chemical even though it did not have a high ranking based on indicator scores. Mercury was chosen because of its environmental toxicity and because it was found in sediments and surface waters at concentrations above background.

Although arsenic had a high ranking among carcinogens, it was not included as an indicator chemical for several reasons. First, the high ranking of arsenic in ground water is due to the detection of arsenic in a residential well upgradient of the landfill. Further, average arsenic concentrations in upgradient and downgradient monitoring wells are nearly identical. Second, the high ranking of arsenic in soil is based on a sample collected in the agricultural field west of the landfill and may be due to the use of agricultural pesticides. Finally, although arsenic ranked high in both surface water and sediment, most of the surface water results and all of the

sediment results were questionable because of analytical quality assurance/quality control problems.

1.4.2.2 Organic Indicator Chemicals

Of the organic indicator chemicals identified, benzene was chosen because it is a potential human carcinogen and because of its presence in ground water.

Chlordane was found in both soils and sediments and was chosen to represent the pesticide group. The next contaminant chosen, 4-methylphenol, does not appear on any of the ranking lists because it does not have a toxicity constant. However, 4-methylphenol was found in sediment samples at verifiable concentrations.

Polychlorinated biphenyls (PCB) were included because of their presence at concentrations above background levels in soils, sediments, and surface water. PCBs are potential human carcinogens and bioaccumulate in biological systems.

Polynuclear aromatic hydrocarbons (PAH) were chosen because they were found in the soils and sediments at elevated concentrations. PAH compounds are toxic to humans and several PAHs are classified as potential human carcinogens. To evaluate this group of chemicals, PRC will consider six specific PAHs that are potential carcinogens. These include benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(b)fluoranthene, indeno(1,2,3-c,d)pyrene, benzo(a)anthracene, and chrysene. Tetrachloroethene was chosen because it was found in ground water and surface water and it is representative of the chlorinated hydrocarbons identified at the site.

CHAPTER 2

ENVIRONMENTAL FATE AND TRANSPORT

A comprehensive understanding of a chemical's movement and transformation within and across various environmental media is necessary to evaluate its potential hazard to human health and the environment. This chapter addresses the fate and transport of the contaminants of concern that represent the substances identified at Bowers Landfill. These representative substances include heavy metals (barium, lead, and mercury) and organic hydrocarbons (benzene, tetrachloroethene, 4-methylphenol, chlordane, polychlorinated biphenyls, and polynuclear aromatic hydrocarbons).

2.1 FACTORS AFFECTING FATE AND TRANSPORT

The major factors that affect fate and transport of contaminants from Bowers Landfill are the geology, hydrology, hydrogeology, and climatology of the area. Each of these factors is discussed in Sections 2.1.1 through 2.1.4.

2.1.1 Geology

The Bowers Landfill area is underlain by unconsolidated alluvial and glacial deposits that overlie shale bedrock. Unconsolidated materials in the site area fill a buried valley. Alluvial deposits are largely floodplain deposits of the current Scioto River system. These deposits overlie and abut a complex glacial terrain.

The Bowers site overlaps two glacial regimes, one east and one west of the site. Immediately to the east are several large eskers composed of coarse to fine grained materials. The depth of the esker deposits is not known, but quarrying activities immediately to the east have extended below the level of the landfill berm. These deposits comprise a linear ridge that trends north to south and extends to a height of 40 to 50 feet above the landfill. Loess deposits were also noted east of the site in the upland area. These loess deposits are silty to clayey in texture and form a relatively impermeable layer where not disturbed by quarrying activities.

To the west and north, surficial alluvial overbank deposits have been identified. The overbank deposits consist largely of clays and silt and extend to a

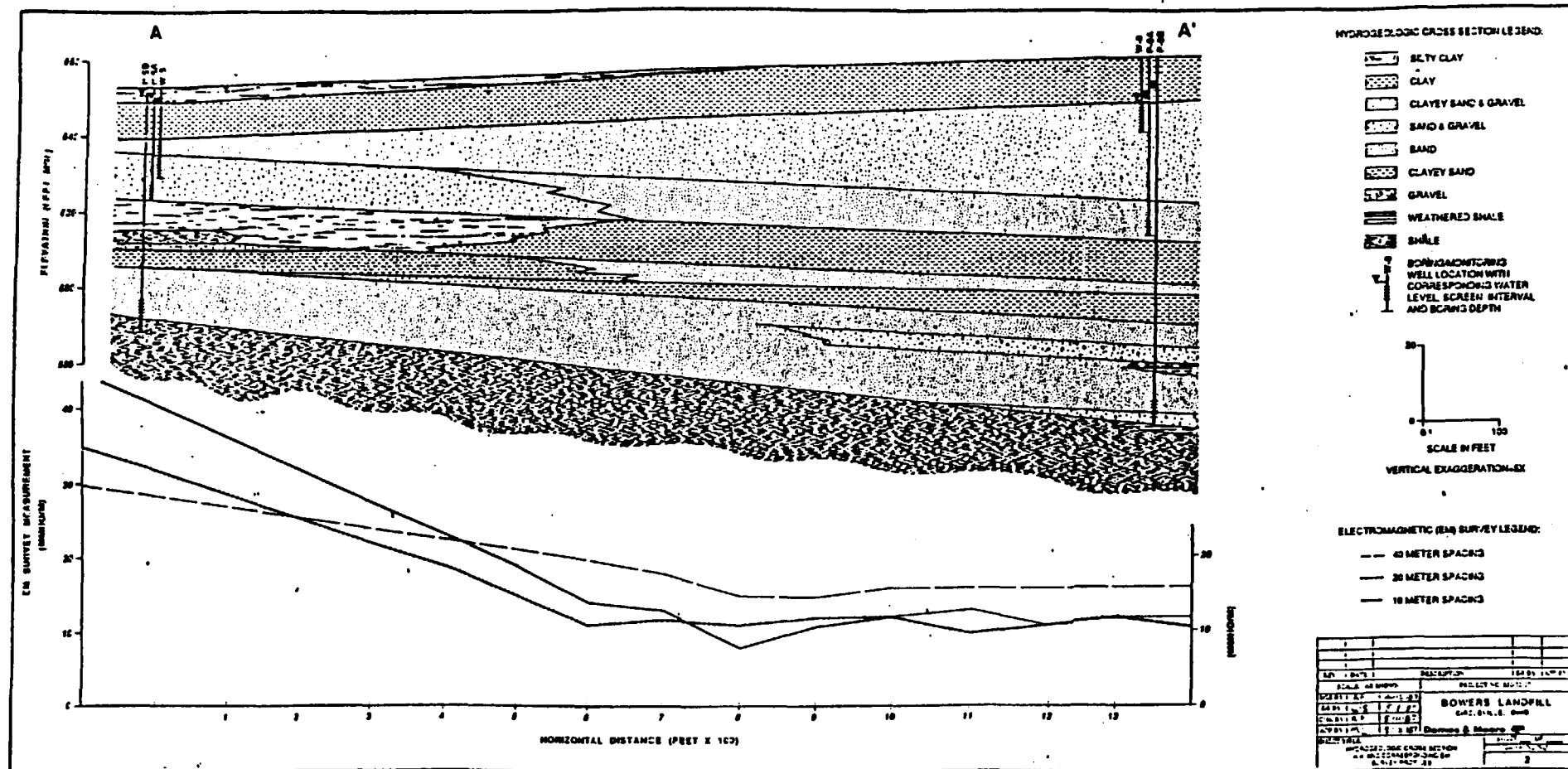
depth of about 10 feet (see Figure 2-1). It is not clear whether these clayey deposits extend below the landfill or whether landfilling activities have penetrated the clay layer.

Glacial deposits underlie the overbank deposits to the west and esker deposits to the east. These glacial deposits extend to a depth of 40 to 100 feet below the ground surface and generally consist of three interlayered deposits: (1) a brown sand and gravel deposit, (2) a gray silt-clay deposit, and (3) a gray sand deposit with lesser amounts of gravel (Dames & Moore, 1987a). The brown sand and gravel deposit (upper sand) exhibits somewhat variable thickness and degree of sorting. The average thickness of this unit is approximately 25 to 30 feet. The sand and gravel deposit is, in most locations, underlain by the relatively thick (10 to 20 feet) gray silt-clay deposit, which may be glacial till. The gray sand deposit (lower sand) underlies the silt-clay deposit at all locations except well location P-7a. This material appeared to be more well sorted and uniform than the shallower deposits. These three deposits were laid down in a highly complex glacial environment. The lateral continuity of these units is unknown. However, Dames & Moore believes that the intervening till acts as an aquitard between the two sand deposits.

A bedrock formation, the Ohio Shale of Devonian Age, underlies the alluvial and the glacial deposits. This bedrock formation is several hundred feet thick and is characterized as an impermeable, carbonaceous shale (Dames & Moore, 1987b).

At the Bowers Landfill site, shale bedrock was encountered at a depth of 40 to 100 feet below ground surface. The bedrock is characterized as black shale, weathered at the bedrock surface and dense and competent below. Pyrite nodules were observed in most of the bedrock samples (Dames & Moore, 1987a). The apparent bedrock surface dips to the south and west from a bedrock high located just north of the site (Dames & Moore, 1987a). However, exploratory borings at well location P-5b indicated local variations in the depth to bedrock of more than 20 feet over very short lateral distances.

FIGURE 2-1 TYPICAL GEOLOGIC CROSS-SECTION WEST OF LANDFILL



Source: Dames & Moore, 1987a

2.1.2 Hydrology

Bowers Landfill lies within the Scioto River floodplain. The river drains an area of 3,217 square miles upstream of the site. It flows south from an area northwest of Columbus and empties into the Ohio River near Portsmouth, Ohio (Dames & Moore, 1987a).

Recent unpublished data approximate flood flows and associated stages in the vicinity of the landfill area as follows (Dames and Moore, 1987a):

<u>Flood Return Period (years)</u>	<u>Discharge near Circleville (cfs)</u>	<u>Water Stage near Circleville (Feet, MSL)</u>	<u>Water Stage near Site (Feet, MSL)*</u>
1	30,200	660.9	662.3
2	40,200	662.9	664.3
5	57,000	664.5	665.9
10	74,800	665.9	667.3
20	94,000	667.4	668.8
50	128,000	669.6	671.0
100	157,900	671.4	672.8

- * Dames & Moore added 1.43 feet as a correction to the U.S. Army Corps of Engineers' data on Circleville to compensate for elevation changes.

Based on water levels at various flood stages, the cultivated land west and north of the landfill may flood every 1 to 2 years. The northern half of the landfill may flood every 5 years. Finally, the entire landfill may flood every 20 years (Dames and Moore, 1987a). Flow duration and flow stage curves for the Scioto River and the Bowers Landfill area show that the field west of the landfill is likely to be flooded about 29 days (usually in winter and spring) in an average year. (Burgess & Niple, 1981) It should be noted that two flood events were observed in 1986 that inundated most of the areas to the east, west, and north of the landfill.

The western leg of the landfill has a depression at its south side that collects landfill runoff; runoff to the north is uncontrolled. Two depressions parallel the landfill's north to south leg. The depression on the west side does not have a discrete discharge point, but rather overflows directly to the adjacent field. The depression on the landfill's east side is more pronounced, similar to a ditch. This ditch primarily flows south to a ponded area; runoff then flows by an underground

discharge pipe directly to the Scioto River. However, the ditch is open at the north end and probably discharges north during moderate to high flow events.

Quarries accumulate runoff to the east, northeast, and south of the landfill. The quarries to the east and south may contain water throughout the year.

2.1.3 Hydrogeology

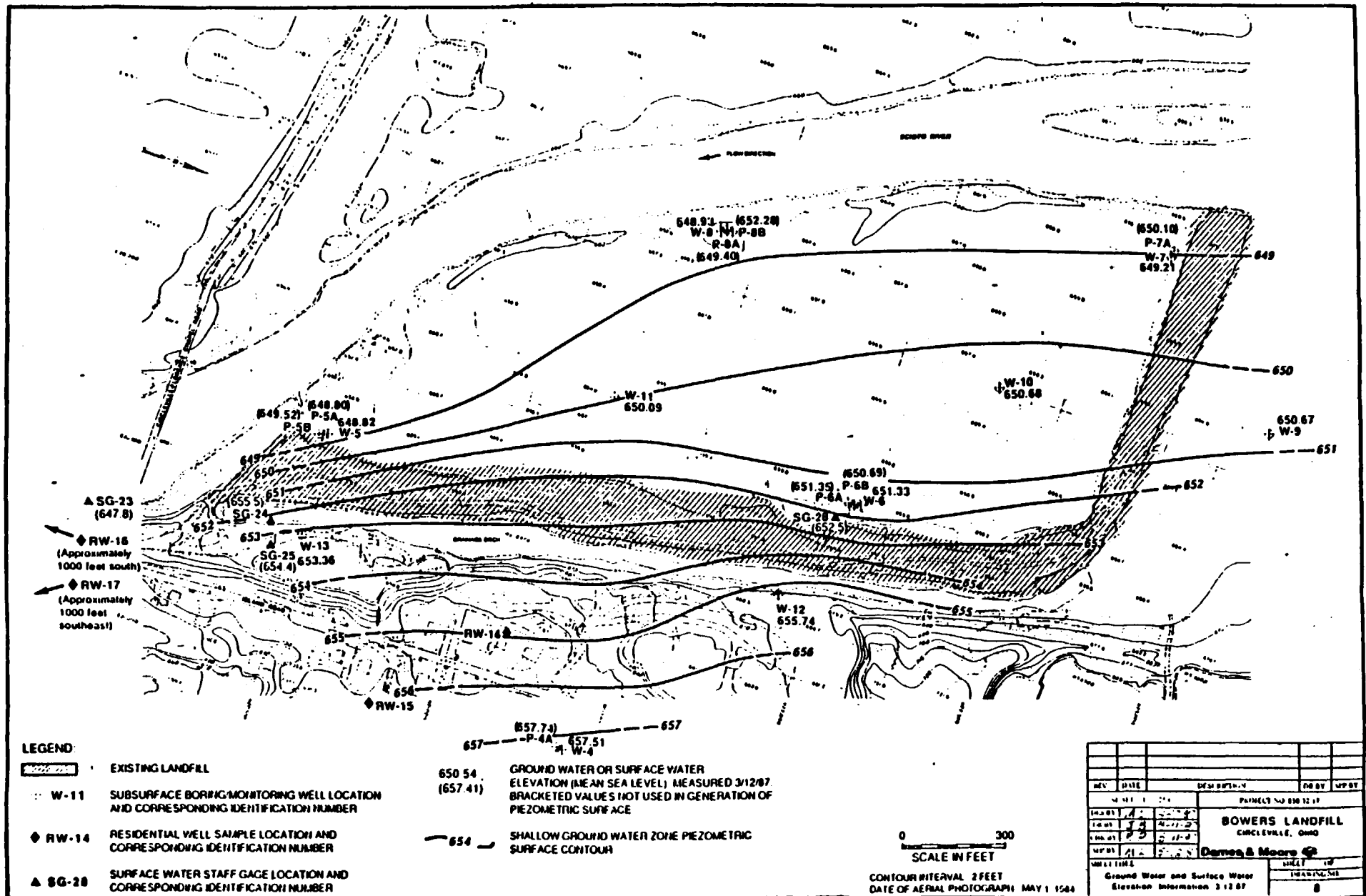
Burgess & Niple installed three monitoring wells adjacent to the landfill in 1981 (MW-1, MW-2, and MW-3 on Figure 1-3). Samples from the downgradient wells indicated contamination with volatile organic constituents (Burgess and Niple, 1981). Dames & Moore plugged one of these wells and installed 18 additional wells in 1986. These wells were all installed using a hollow stem auger. Wells were screened at one of three intervals: 10 as shallow wells, W-4 through W-13; 5 as intermediate wells, P-4A through P-8A; and 3 as deep wells, P-5B, P-6B, and P-8B. Two additional deep wells, P-12B and P-13B, were installed east of the landfill in 1988. Wells were constructed of stainless steel; sand packs were installed in the annular space around the screened interval; bentonite slurry was added to a depth of 2 feet below ground surface; and concrete surface seals were installed.

As mentioned in Section 2.1.1, the upper 40 to 100 feet beneath the Bowers Landfill area is characterized by unconsolidated alluvium and glacial deposits. The unconsolidated deposits yield abundant water and are heavily used as a ground-water resource. non responsive

The underlying bedrock, a relatively impermeable shale is not used for local ground-water withdrawal.

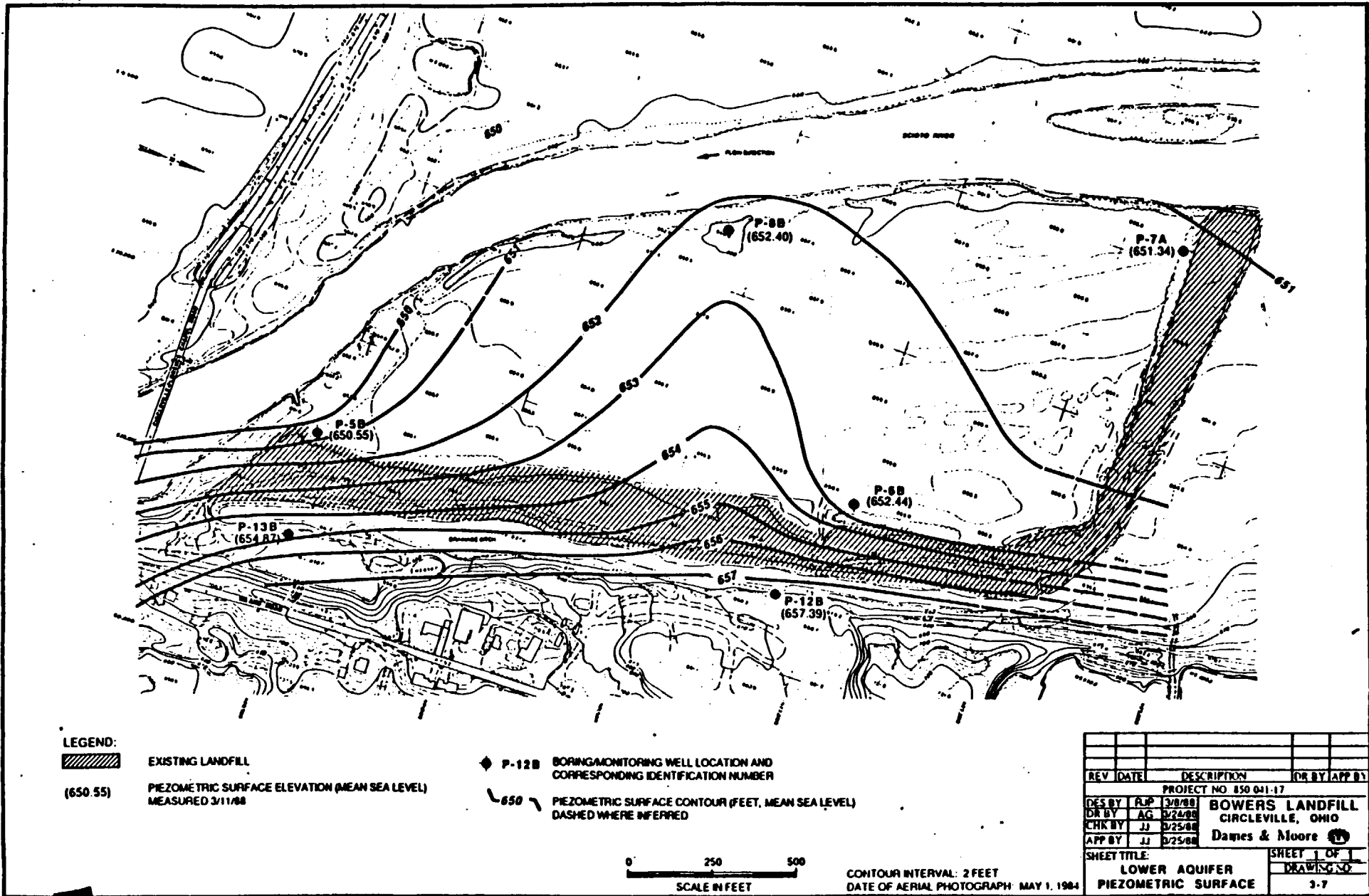
Two water-bearing units have been identified. These are the upper and lower glacial sand and gravel deposits discussed in Section 2.1.1. Dames & Moore constructed potentiometric maps for ground water within the upper and lower water-bearing units. These are shown as Figures 2-2 and 2-3. Ground-water flow in both units is west to southwest toward the river.

FIGURE 2-2 POTENTIOMETRIC MAP FOR SHALLOW WELLS



Source: Dames & Moore, 1987a

FIGURE 2-3 POTENTIOMETRIC MAP FOR DEEP WELLS



Source: Dames & Moore, 1988.

According to Dames & Moore (1987a, 1988), the upper and lower aquifers appear to be separated by lower permeability till. At four of the five locations where wells are screened in both the upper and lower aquifers, Dames & Moore observed a vertical variation in piezometric head between the two aquifers. This evidence suggests that, at some locations, the two aquifers are hydraulically separate and act as distinct water-bearing units. However, at location 12 just east of the landfill (see Figure 1-4), the intervening till layer is not present and there is vertical hydraulic gradient between the two units. Thus, for part of the site, the two units may be interconnected and act as a single aquifer.

Recharge to the upper water-bearing unit in the Scioto River valley generally occurs through infiltration from precipitation, from infiltration of Scioto River water during high stage conditions, and from underflow through buried valley walls (ODNR, 1965). Local recharge in the Bowers Landfill area has been impacted by quarrying and landfilling activities. Where present, clayey alluvial deposits are believed to inhibit recharge from the Scioto River and from precipitation in the floodplain area.

Ground-water flow rates have been estimated for both the upper and lower units. The observed piezometric gradient in the uppermost unit is on the order of 10^{-3} to 10^{-2} feet per foot. The hydraulic conductivity of the sand and gravel is estimated to be on the order of 400 feet per day. Therefore, an approximate ground-water flow rate of 0.4 to 4 feet per day may be assumed. The observed piezometric gradient, hydraulic conductivity, and approximate ground-water flow rate for the lower unit are similar (Dames & Moore, 1988). These values, however, may be low. Additional site-specific hydraulic information is necessary to quantify hydraulic conductivity and flow rates.

2.1.4 Climatology

Bowers Landfill is located in Pickaway County, Ohio, and is within the Scioto River floodplain. Rainfall and snowfall make up the average annual precipitation of 38 inches. In general, precipitation occurs in the form of rain between April and September. An average seasonal snowfall of 13 inches accounts for most wintertime precipitation. The average monthly precipitation in the Pickaway County is as follows (Dames & Moore, 1987a):

January	2.54 inches
February	2.42 inches
March	3.61 inches
April	3.88 inches
May	4.16 inches
June	3.54 inches
July	3.91 inches
August	3.24 inches
September	3.33 inches
October	2.05 inches
November	2.76 inches
December	2.59 inches

The climate in Pickaway County is reportedly characterized by cold, windy, winters and hot, humid summers (Dames & Moore, 1987a). The average maximum and minimum temperatures recorded in the area are 73 °F and 24 °F, respectively. The highest and lowest recorded temperatures are 103 °F and -17 °F, respectively (CH2M Hill, 1983).

The prevailing winds are from the south and southwest. Average daily wind speed is highest (11 mph) in March. Thunderstorms occur about 40 days each year, primarily in the summer. Also, the area is hit by tornados and severe thunderstorms at times (CH2M Hill, 1983).

2.2 PROCESSES AFFECTING FATE AND TRANSPORT

Processes that affect the distribution of a contaminant in the environment include transfer processes (sorption, bioaccumulation, volatilization) and transformation processes (photolysis, oxidation, hydrolysis, biotransformation/biodegradation). These processes are defined in Appendix B. In general, the extent to which these processes affect fate and transport depends on the environmental medium and the physicochemical properties of the contaminant.

The environmental behavior of each contaminant of concern at Bowers Landfill is discussed in the following sections. These discussions emphasize the predominant fate processes in each environmental medium and the main transport mechanisms between media at Bowers Landfill. Where possible, information available in the literature is summarized; if such information was not available, PRC predicted the contaminant's behavior based on its physicochemical properties.

2.2.1 Metals

Techniques for predicting the behavior (movement and transformation) of metals are strictly qualitative. Kotuby-Amacher and others (1986) stated that the movement of metals in landfill leachates can be qualitatively assessed based on the physical and chemical properties of the leaching solution and several soil characteristics. Properties of the leaching solution include viscosity, surface tension, pH, total soluble iron content, and amount and strength of organic and inorganic complex formers. Soil characteristics include particle size, surface area, cation exchange capacity, pH, organic matter content, microbial activity, and others. Fungaroli and Steiner (1979) reported that dispersion due to hydraulic gradients within soil voids has the greatest effect on leachate migration into ground water. Conversely, adsorption retards leachate movement.

Knowledge of the specific metal species present is important in evaluating the metal's fate and transport. The specific metal species present is determined by the oxidation-reduction potential (Eh) and pH of the media. For example, under normal Eh-pH conditions of natural waters, the pentavalent and the trivalent forms of arsenic are the dominant species. Although pH data for surface and ground waters are available, data on other physicochemical properties of soils and waters at the Bowers Landfill site are not available.

In some instances metal exhibit similar behavior. For example, metals generally do not volatilize; however, some biologically mediated forms are known to volatilize. In addition, most metals bioaccumulate. The behavior of specific metals of concern at Bowers Landfill is discussed in the following sections.

2.2.1.1 Barium

The ultimate fate of barium is expected to be sorption onto soils and sediments. Very limited information is available in the literature on barium fate and transport processes. When specific information was not available describing barium's behavior in a particular process, PRC assumed that barium behaves like most heavy metals.

In natural environments, barium exists mainly in the sulfate or the carbonate form. Most natural waters contain sulfate and carbonate. If barium is also present, only trace amounts of dissolved barium sulfate would be found because barium sulfate has a very low solubility.

Barium is expected to sorb strongly onto clays and organic matter (U.S. EPA, 1984b). Lagas and others (1984) conducted laboratory column studies to observe the behavior of barium in landfills. They noted that 18 to 39% of the barium leached out of the column and appeared to be complexed with organics. In addition, most of the barium was present as carbonate or sulfate compounds. Gerritse and others (1982) observed an increase in barium mobility in leachate from sandy soils due to the presence of dissolved organics and ions in the leachate.

Other fate processes of barium include volatilization, hydrolysis, and oxidation. Barium, like most heavy metals, is not expected to volatilize due to its low vapor pressure. Barium's reaction with cold water produces hydrogen gas; it also reacts readily with oxygen (National Library of Medicine, 1987).

2.2.1.2 Lead

The presence of lead in natural waters is influenced by pH, which in turn determines the lead complexes that are formed. Lead can exist in three oxidation states -- 0, +2, and +4. Lead forms stable soluble complexes with inorganic anions such as OH^- , Cl^- , CO_3^{2-} , and HCO_3^- . These complexes, because of their stability, increase the soluble lead concentration in aquatic environments. In fresh water, the free lead ion is generally the dominant form at pH less than 7.5; lead carbonate dominates at pH greater than 7.5 and less than 9.5 (Long and Angino, 1977).

Humic and fulvic acids derived from vegetation decay are capable of binding lead, even at a pH of 3.0 (Guy and Chakrabarti, 1976). At landfill sites such as Bowers, where concentrations of humic substances are expected to be high, considerable amounts of lead could be bound to the humic substances. Lead can sorb strongly onto soils containing organic matter and clay. It also forms complexes with humic and fulvic acids. Ramamoorthy and Kushner (1975) found that almost all the dissolved lead in river water was complexed to organic ligands.

Pita and Hyne (1975) found that lead primarily sorbed onto clays. The data from another study (Huang and others, 1977) indicates that lead sorption is highly pH dependent, and above pH 7 essentially all the lead is in the solid phase. The addition of humic acids that complex lead readily increased the soil affinity for lead. Moore and Ramamoorthy (1984) stated that sorption of lead to sediments is correlated to organic content and particle size.

Lead can be biotransformed by microorganisms present in sediments. One such biotransformation process is biomethylation, which produces tetramethyl lead, a volatile compound. Tetramethyl lead leaves the sediments and is either oxidized in the water column or enters the atmosphere (Wong and others, 1975). This process enables lead in the sediments to be reintroduced to aqueous or atmospheric environments. The importance of methylation as a fate mechanism, however, is still uncertain.

A variety of aquatic organisms can bioaccumulate lead. Callahan and others (1979) stated that oysters and mussels can accumulate high levels of lead, while fish accumulate very little. Bioconcentration factors range from 60 to 200 and are greatly affected by the pH of the environment. At the Bowers site, bioaccumulation of lead is possible among organisms in surface waters. A microcosm study conducted with algae, snails, mosquito larvae, mosquito fish, and microorganisms indicates that lead does not biomagnify (Callahan and others, 1979).

No specific information was found on photolysis of lead in natural water or in the soil/water matrix.

2.2.1.3 Mercury

In the natural environment, mercury can exist in three oxidation states -- 0, +1, +2. The presence of the particular species depends on pH, redox potential, and the nature of complex forming anions. In well-aerated waters, the +2 form predominates while elemental mercury is present under reducing conditions. At the Bowers Landfill site, where the pH of the surface and ground waters are greater than 4, mercury is probably present as elemental mercury.

Mercury also forms stable complexes with organic compounds. The strongest complexes are formed with organics containing sulfhydryl groups followed by amino acids and hydroxy carboxylic acids (Moore and Ramamoorthy, 1984). Mercury can also be transformed to methylated mercury compounds both biologically and abiotically in low pH and reducing environments (U.S. EPA, 1981).

Mercury shows a strong tendency to sorb onto various surfaces. Moore and Ramamoorthy (1984) reported a partition coefficient of 1.34 to 1.88×10^5 for mercury between suspended solids and water. Thomabulaningam and Pickering (1985) observed that the presence of humic acids in the sediment greatly increased mercury (+2) sorption. Although the sorption capacity was lower than other divalent cations, such as lead, cadmium, zinc, and copper, the retention rate was high enough to ensure that most of the mercury was bound to sediments.

Volatilization may be an important fate process for metallic mercury, due to its relatively high vapor pressure compared to other metals (Callahan and others, 1979). Formation of methylated mercury would also enhance the volatilization process.

Bioaccumulation of mercury by fish has been well documented. Moore and Ramamoorthy (1984) stated that mercury present in fish tissues is mostly in the methylated form. Organic mercury can enter fish at a faster rate than inorganic forms. It is also very persistent; according to Callahan and others (1979), the deputed half-life of mercury is 1 to 3 years, which is probably the longest among metals.

Most mercurial compounds can be converted to methyl mercury by microorganisms. The rate of transformation depends on pH, temperature, redox potential, and availability of complexing agents. Highly organic sediments favoring bacterial growth have higher potential for methylation than inorganic sediments.

2.2.2 Organic Compounds

Several transfer processes that affect the movement of organic contaminants can be estimated from physicochemical properties such as solubility, Henry's Law Constant, and octanol/water partition coefficient. Relevant physicochemical

properties of the contaminants of concern at Bowers Landfill are listed in Table 2-1.

Several relationships are available for estimating sorption from octanol/water partition coefficients (K_{ow}) or from water solubility. The error associated with these estimation techniques is generally less than an order-of-magnitude (Lyman, 1982). For hydrophobic compounds, sorption estimates based on K_{ow} are expected to be more reliable than estimates based on solubility.

The parameter obtained from K_{ow} or solubility is K_{oc} , which is the sorption coefficient normalized for soil organic carbon. K_{oc} values may be used for ranking and comparing a chemical's potential for leaching. Based on the classification of soil mobility potential developed by McCall and others (1980), any compound with a K_{oc} value above 5×10^3 may be considered immobile; compounds with a K_{oc} value below 150 may be considered highly mobile.

Estimated bioconcentration factors (BCF) may aid in understanding a chemical's potential for bioaccumulation. BCF is defined as the ratio of the equilibrium concentration of a chemical in an organism to its concentration in water. Callahan and others (1979) noted that compounds with a solubility greater than 50 mg/L or with $\log K_{ow}$ less than 2 do not bioaccumulate to a significant degree. Those with $\log K_{ow}$ values higher than 4 are believed to bioaccumulate to a high extent.

The Henry's-Law coefficient (H) indicates a chemical's potential to volatilize from soil and water. The higher the value of H, the higher the potential for volatilization.

Generalized predictions about fate via transformation processes are not possible for most compounds.

2.2.2.1 Benzene

Major fate processes for benzene include volatilization and biodegradation. Benzene sorption to soils and sediments is probably low. As indicated in Table 2-1, the log octanol/water partition coefficient ($\log K_{ow}$) for benzene is 2.12, and the K_{oc} is 83. These values indicate that sorption to organic material is low and that

TABLE 2-1
PHYSICAL PROPERTIES OF ORGANIC INDICATOR CONTAMINANTS¹

	Molecular Weight	Solubility in water (mg/L)	Henry's Law Constant (atm m ³ /mol)	Log Octanol/Water Partition Coefficient	Koc (mL/g)	Fish BCF (L/kg)
Benzene	78	1,750	5.59×10^{-3}	2.12	83	5.2
4-Methylphenol ²	108	31,000	1.1×10^{-6}	1.97	500	0
Chlordane	410	0.56	9.63×10^{-6}	3.32	1.4×10^5	14,000
Tetrachlorethene	166	150	2.59×10^{-2}	2.6	364	31
PCBs	328	3.1×10^{-2}	1.07×10^{-3}	6.04	5.3×10^5	1×10^5
PAHs ³	228-278	5.3×10^{-4} $- 1.4 \times 10^{-2}$	6.86×10^{-8} $- 1.19 \times 10^{-5}$	5.6 - 6.62	2×10^5 $- 5.5 \times 10^6$.. ⁴

Note: 1 Physical property values obtained from U.S. EPA, 1986a. Superfund Public Health Evaluation Manual, Office of Emergency and Remedial Response, Washington, D.C. EPA 540/1-86-060.

2 4-Methylphenol is also known as p-cresol. Physical properties data presented in this table are average values for all isomers of cresol.

3 Includes benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

4 Fish BCF values are not available for these PAHs.

benzene is expected to be highly mobile in soil-water environments. However, the degree of sorption may increase if the organic content of the sediment increases.

Volatilization of benzene is expected due to the contaminant's relatively high vapor pressure. The rate of benzene volatilization from a water column (1-meter thick) has been studied; the half-life was estimated to be 4.81 hours at 25 °C and 5.03 hours at 10 °C (Mackay and Leinonen, 1975).

- Benzene is not expected to bioaccumulate in organisms at Bowers Landfill because it has a water solubility of 1,750 mg/L, a log K_{ow} of 2.12, and a bioconcentration factor of 5.2.

Callahan and others (1979) have suggested that oxidation of benzene in surface water is unlikely. However, benzene that reaches the atmosphere is expected to be oxidized. Once in the atmosphere, benzene is attacked by hydroxyl radicals. Callahan and others (1979) inferred from the work of Altshuller (1962) that the half-conversion time of benzene via photooxidation is between 20 and 50 hours.

Benzene is listed as one of the pollutants that are biodegraded in biological treatment processes and in media where microorganisms are present. Initial reaction products in the bacterial oxidation of aromatic hydrocarbons such as benzene involve the formation of cis-dihydrodiols, which undergo further oxidation to yield catechols (Gibson and others, 1968). Wilson and McNaab (1983) predicted that benzene could probably biodegrade under aerobic conditions in ground water. They did not expect degradation under anaerobic conditions. Delfino and Miles (1985) observed complete aerobic biodegradation of benzene in 16 days in a simulated ground-water environment, but benzene was not degraded after 96 days under anaerobic conditions. Callahan and other (1979) noted that some species of soil bacteria can biodegrade benzene.

Other transformation reactions are not expected to be significant fate processes for benzene at Bowers Landfill. Photolysis of benzene on the earth's surface is not expected to occur. It is generally known that ozone in the atmosphere prevents light wavelengths shorter than 290 nm from reaching the earth's surface. Photolysis is not expected since benzene does not absorb wavelengths of light longer than 260 nm. Also, hydrolysis of benzene is unlikely

since nucleophilic attack of the aromatic ring by water or hydroxide ions is impeded by benzene's negative charge-density (Morrison and Boyd, 1973).

2.2.2.2 Chlordane

Technical chlordane is a widely used pesticide that contains several chlordane isomers. Most of the information available in the literature is on the behavior of a few major isomers. In the discussion that follows, behavior of the cis and trans isomers is discussed if information on chlordane is not available.

Major fate processes of chlordane include sorption and bioaccumulation.

Based on chlordane's K_{oc} value of 1.4×10^5 , it is expected to sorb strongly to soils and sediments. Callahan and others (1979) noted that sorption is probably an important fate process for chlordane.

While volatilization of chlordane is probably a significant fate process from surface waters, the presence of soils or sediments could inhibit the process. Based on experiments conducted by several researchers, Callahan and others (1979) reported that volatilization of cis- and trans-chlordane proceeded rapidly from flasks containing no sediment. When sediments were present, 60 percent of the chlordane was lost within 12 weeks, presumably due to volatilization and biotransformation. Therefore, although an important process, volatilization of chlordane is not expected to be as significant a fate process as sorption.

Based on its BCF value of 14,000 in fish, chlordane is expected to bioaccumulate strongly. Callahan and others (1979) noted that bioaccumulation of chlordane is an important fate process in aquatic environments. Based on its moderate $\log K_{ow}$ value, chlordane is also expected to bioaccumulate in soil organisms present at Bowers Landfill.

PRC could not find any information on the biodegradation of chlordane. Since the compound is designed to be persistent in the environment as a pesticide, chlordane is not expected to biodegrade at a significant rate in soils. Furthermore, chlordane may biodegrade slowly in aquatic systems (Callahan and others, 1979).

Callahan and others (1979) noted that photolysis and hydrolysis are not expected to be significant fate processes for chlordane.

Compared to most pesticides, chlordane is expected to have little potential for contaminating ground water. Rao and others (1985) compared 41 pesticides for their potential to contaminate ground water. In terms of retardation factor, leachability and volatility, chlordane was ranked 40, 27, and 29, respectively.

2.2.2.3 4-Methylphenol

4-Methylphenol is also known as para- or p-cresol. The physical properties data presented in Table 2-1 includes all isomers of cresol.

Based on its K_{oc} value of 500 (U.S. EPA, 1986a), p-cresol is expected to have medium to low mobility in soil-water systems (McCall and others, 1980). However, using the relationships based on $\log K_{ow}$ or solubility presented in Lyman (1982), predicted K_{oc} values would be an order-of-magnitude lower than that reported in U.S. EPA (1986a). Furthermore, K_{oc} values determined from sorption experiments also are much lower than 500. Boyd (1982) conducted sorption experiments with a clay loam soil and reported a K_{oc} of 49. Boyd and King (1984) conducted batch sorption experiments over a 96-hour period with soil containing 4.74 percent organic matter. They reported a sorption coefficient of 1.01, which corresponds to a K_{oc} of 36. Therefore, a K_{oc} of about 50 is apparently more appropriate; thus, p-cresol is expected to be highly mobile. P-cresol present in ground waters or subsurface soil at Bowers Landfill is expected to move along with the water.

PRC could not find any data in the literature on the volatility of p-cresol from soil or water. However, based on its low Henry's Law coefficient and high solubility in water, p-cresol is not expected to volatilize from soils and surface waters at the Bowers site.

Based on its BCF value of 0 in fish and $\log K_{ow}$ of 1.97, p-cresol is not expected to bioaccumulate.

P-cresol is expected to biodegrade under aerobic conditions. Boyd and King (1984) observed complete disappearance within 48 hours from solutions containing 5

to 50 mg/L of p-cresol under aerobic conditions but not under anaerobic conditions. Furthermore, Delfino and Miles (1985) observed complete degradation of p-cresol in less than 8 days under aerobic conditions. Complete anaerobic degradation occurred in less than 41 days. Therefore, p-cresol present at Bowers Landfill is expected to completely biodegrade within a short period of time, irrespective of the environmental conditions.

PRC could not find any information in the literature on photolysis and hydrolysis of p-cresol. However, based on the behavioral similarity of p-cresol and phenol, p-cresol in the atmosphere is expected to photodegrade. In aquatic systems, biodegradation will dominate other fate processes.

2.2.2.4 Polychlorinated Biphenyls

Environmental behavior of PCB varies widely depending on the particular Aroclor of concern. Aroclors are mixtures of several PCB congeners. For example, Aroclor 1248 is composed primarily of PCBs containing three to six chlorine atoms. At the Bowers site, Aroclor 1242, 1248, 1254, and 1260 were detected in various media. Most of the information available in the literature is on the transfer and transformation processes of individual PCB congeners or Aroclors.

Sorption on soils at the Bowers site is probably the major factor affecting the distribution of PCBs in the environment.

Other fate processes include bioaccumulation and volatilization. Nau-Ritter and others (1982) and Haque and others (1974) reported sorption coefficients of Aroclor 1254 onto soils with known organic matter content. From these data, PRC calculated K_{oc} values for Aroclor 1254 ranging from 1.3×10^5 to 1.4×10^6 . These values compare well with the value listed in Table 2-1. Based on the classification of soil mobility potential developed by McCall and others (1980), PCBs would be considered immobile. The presence of organic solvents, however, could facilitate the mobilization of PCBs (Griffin and Chou, 1981).

Soils at Bowers Landfill may act as a sink for PCBs. Working with hexachlorobiphenyl, a PCB congener, Horzempa and DiToro (1983) found that once sorbed, this compound was resistant to desorption. They also cautioned that using

sorption coefficients to predict releases from sorbents might result in overestimation of desorption. Therefore, following rainfall at Bowers Landfill, only small amounts of PCBs would be released to the water that contacts the soil.

PCBs are persistent in organisms due to PCBs' characteristically high tendency to bioaccumulate. In addition, PCBs biodegrade very slowly. Although biomagnification does occur with PCBs, it appears that the partition coefficient for each organism in the food chain determines the ultimate level of PCBs rather than the organism's position in the food chain (Clayton and others, 1977). The BCF value for PCBs in fish is listed at 1×10^5 . This value indicates that PCB concentrations in aquatic organisms will be approximately 10^5 times the concentrations in water. This estimated value is similar to the measured log BCF value of 5.28 for Aroclor 1260 in fathead minnows (Leifer and others, 1983). Leifer and others (1983) reported the results of several laboratory experiments with hexachlorobiphenyl; the reported log BCF values for different aquatic organisms ranged from 4.62 to 6.03.

Bowers Landfill hosts several terrestrial organisms. Although data on bioaccumulation of PCBs in terrestrial animals are not available, the potential and extent of bioaccumulation can be assumed to be similar to those for aquatic organisms.

Several researchers have studied volatilization of PCBs from water and soils. Haque and others (1974) reported negligible volatilization of Aroclor 1254 from soils. The volatilization was greater from sand surfaces, which they attribute to the lower sorption capacity of sands. They also stated that volatilization may increase with increasing temperature and that volatilization may also increase if PCBs are present as a separate phase. Mackay and Leinonen (1975) calculated the volatilization half-life of Aroclor 1260 from a 1-meter-deep water column and reported a value of 10.2 hours. They stated that due to high activity coefficients of Aroclor 1260 in water, the evaporation rates are higher than what would be expected based on the high molecular weight and low vapor pressure. Other studies, however, indicate much higher half-life values. Callahan and others (1979) reported results from a study that showed a 67 percent loss of Aroclor 1260 from river water after 12 weeks; the rate decreased to 34 percent after 12 weeks when sediment was added.

Hydrolysis does not appear to be an important fate process since PCBs are strongly resistant to both acidic and basic hydrolysis (Callahan and others, 1979).

Although rate of photolysis for PCBs is very low, it is significant because other transformation processes may not degrade or destroy the heavier PCBs. Most of the information available in the literature discusses photolytic breakdown of PCBs in water solutions or in the presence of solvents. Experimental investigations in a 4:1 acetonitrile-water solution conducted by Bunce and Kumar (1978) showed that each highly chlorinated PCB molecule, such as Aroclor 1260, lost at least one chlorine atom annually. Pal and others (1980) stated that PCBs applied to surface soils may not photolyze because evidence indicates that oxygen suppresses photolysis. In localized anaerobic zones, photolysis of highly chlorinated PCBs might occur.

There are no experimental data showing PCB biodegradation under anaerobic conditions. Leifer and others (1983) reported that PCBs do degrade under aerobic conditions, and the rate of biodegradation decrease with increasing numbers of chlorine atoms. The half-life values reported for soils and fresh waters range from 1 to 10 days for PCBs with one or two chlorine atoms compared to more than a year for PCBs with five or more chlorine atoms. Callahan and others (1979) discussed several studies on the biodegradation of heavier PCB molecules. In one study, Aroclor 1254 was biodegraded between 19 to 38 percent over 48 hours in an activated sludge experiment. Two other studies reported no biodegradation of Aroclor 1260 or pentachlorobiphenyl in aqueous solutions. Pal and others (1980) stated that rates of PCB degradation in soils are relatively slow. They noted that organisms usually require years to adapt to a new chemical, but that PCBs at high concentrations might inhibit microbial activity.

2.2.2.5 Polynuclear Aromatic Hydrocarbons

Sorption to soils and sediments is expected to be the major fate process for polynuclear aromatic hydrocarbons (PAHs).

Polynuclear aromatic hydrocarbons are defined as compounds containing three or more aromatic rings. PAHs have very high K_{oc} and $\log K_{ow}$ values and a very

low solubility in water. Based on these physical properties, sorption is expected to be the most dominant fate process for these compounds.

Most of the K_{ow} - K_{oc} relationships available in the literature were developed using PAHs as sorbates. Therefore, available K_{oc} values provide good estimates of sorption potential. Based on the K_{oc} values listed in Table 2-1, the PAHs of concern at Bowers Landfill would be considered extremely immobile (McCall and other, 1980). U.S. EPA (1982a) discussed a sorption study conducted with benzo(a)pyrene, several fresh water sediments, and a clay sample. The K_{oc} values obtained using the fresh water sediment samples were in close agreement with the K_{oc} value listed in U.S. EPA (1986a) for this compound. The K_{oc} value obtained with the clay sample, however, is little over a factor of two times the K_{oc} value for benzo(a)pyrene. This is, however, expected since the K_{oc} - K_{ow} relationships are not valid for sorbents with a carbon content of less than 0.1 percent. The K_p value (sorption coefficient), however, suggests that sorption could still be significant. It can be concluded that the PAHs of concern at Bowers Landfill would be sorbed onto sediments and soils. Transport of these PAHs could still occur due to migration of particulate matter associated with soil-water runoff.

Henry's Law coefficients of PAHs decrease with increasing number of aromatic rings, indicating that volatilization from soil and water becomes less pronounced as molecular weight increase. However, volatilization rates are still slow for most PAHs. Callahan and other (1979) noted that volatilization may not be as important a fate process for PAHs as sorption. Callahan and others (1979) discuss a study in which the volatilization half-lives of benzo(a)pyrene and benzo(a)anthracene were measured as 22 and 89 hours, respectively, from a rapidly stirred aqueous solution. These rates are quite slow compared to rates of direct photolysis. Furthermore, in natural environments, where the PAHs are expected to be associated with soils, sediments, and particulate matter, volatilization could be a very slow process.

Although fish BCF values are not available for these compounds, low water solubility and high K_{ow} values suggest that bioaccumulation would still be significant. Benzo(a)pyrene, a compound with five aromatic rings, has been shown to bioaccumulate strongly in several aquatic species and bacteria (Callahan and others, 1979). Lu and others (1977) stated that fish do not bioaccumulate benzo(a)pyrene; however, other aquatic organisms do. Therefore, it is probable that

PAHs bioaccumulate in soil organisms present at Bowers Landfill. Callahan and others (1979), however, noted that PAHs containing four or fewer aromatic rings may be rapidly metabolized and eliminated by organisms; therefore, bioaccumulation is a short-term process.

Available information in the literature indicate that photolysis from surface water is probably an important fate mechanism for PAHs. Although data are available for benzo(a)pyrene and benzo(a)anthracene only, other PAHs probably react in a similar way. Callahan and others (1979) discussed several studies which indicate that the photolytic half-lives of these compounds dissolved in water are on the order of hours. However, rates of photolysis were found to be much slower in natural environments. U.S. EPA (1982a) discussed studies of benzo(a)pyrene photolysis when the compound was sorbed onto humics, calcite particles, or suspended matter. The rates of photolysis were much higher from these systems.

Wilson and McNaab (1983) predicted that biodegradation of PAHs containing four or more aromatic rings is unlikely in aerobic aquifers and is not expected in anaerobic aquifers. However, biodegradation of compounds with two or three aromatic rings has been reported in the literature. Callahan and others (1979) noted that biodegradation may be the ultimate fate process for PAHs with less than four aromatic rings.

Hydrolysis is not expected to be a significant fate process for PAHs.

2.2.2.6 Tetrachloroethene

Major fate process for tetrachloroethene is volatilization. Other fate processes include sorption, bioaccumulation, and biodegradation. Based on its K_{oc} value of 364, tetrachloroethene is expected to have a higher sorption potential than benzene, but much less than the other organic contaminants of concern at the Bowers Landfill site. However, tetrachloroethene is still considered to have a medium mobility (McCall and others, 1980). For tetrachloroethene sorption onto soils, Friesel and others (1984) reported a K_{som} (sorption coefficient normalized for organic matter) value of 137.7 (approximately equal to a K_{oc} of 237). This K_{oc} value compares well with that reported by U.S. EPA (1986a). Curtis and others (1985) conducted sorption experiments with low carbon aquifer soils and compared

their results with retardation factors (ratio of the velocity of water to the velocity of a contaminant) observed in field studies. Retardation factors in the field ranged between 2.4 and 3.7, while that observed in the laboratory was 3.1. Schwarzenbach and others (1983) estimated retardation factors of 17 for river sediment, 3.3 for an aquifer close to a river, and 1.7 for a glacial aquifer. Thus, although tetrachloroethene does sorb onto soils and sediments, the extent of sorption to soils in the aquifers at Bowers Landfill is expected to be low.

Based on its BCF value of 31 and log K_{ow} of 2.6, tetrachloroethene may have the potential to bioaccumulate. Pearson and McConnell (1975) conducted bioaccumulation experiments with dabs and found BCF values greater than 100 in the liver, but less than 10 in the flesh. Callahan and others (1979) noted that there is no evidence for biomagnification, although weak to moderate bioaccumulation of tetrachloroethene does occur.

Tetrachloroethene present in the surface waters at Bowers Landfill is expected to rapidly volatilize to the atmosphere. Dilling and others (1975) conducted laboratory experiments to determine volatilization rates of tetrachloroethene from aqueous media. The volatilization half-life of 1 ppm tetrachloroethene in water when stirred at 200 rpm was found to be 26 minutes. Jensen and Rosenberg (1975) observed a 50 percent decrease of tetrachloroethene in 8 days from a partially open aquarium. They also showed that tetrachloroethene's rate of volatilization is faster than its rates of photolysis, oxidation, or hydrolysis.

Other fate processes of tetrachloroethene include oxidation, hydrolysis, and photolysis.

Dilling and others (1975) conducted experiments over a period of one year to determine loss mechanisms of tetrachloroethene from aqueous media; they attributed a 13 percent loss to oxidation. Callahan and others (1979) indicated that in the atmosphere, tetrachloroethene reacts with hydroxyl radicals to produce trichloroacetyl chloride and some phosgene. Tetrachloroethene is reported to produce trichloroacetic acid and hydrochloric acid due to hydrolysis (Dilling and others, 1975). However, the rate of hydrolysis appears to be slow. Callahan and others (1979) noted that photolysis of tetrachloroethene is not expected to be a significant fate process.

Tetrachloroethene may biodegrade under certain environmental conditions. Wilson and McNaab (1983) predicted that biodegradation of tetrachloroethene is possible under anaerobic conditions, but not under aerobic environments. In anaerobic ground water, tetrachloroethene sequentially transforms to trichloroethene, then to dichloroethene and finally to vinyl chloride (Wood and others, 1985). Thom and Agg (1975) stated that tetrachloroethene is potentially biodegradable in sewage treatment processes. Tabak and others (1981) showed a 45 percent loss of tetrachloroethene following 7 days of incubation with domestic wastewater.

2.3 MEDIA-SPECIFIC FATE AND TRANSPORT

Contaminants in Bowers Landfill may remain in place, may volatilize into the overlying soil, may leach out into the ground water, or may enter the surface water via ground-water discharge or soil erosion. The following sections discuss contaminant fate and transport within and between media at Bowers Landfill.

2.3.1 Soil Fate and Transport

Soils and sediments at the Bowers site are expected to serve as sink for barium, lead, mercury, PCBs, chlordane, and PAHs. Since the soil acts as a sink, transport may occur due to soil erosion in areas where there is no vegetative cover. These contaminants may subsequently migrate with particulate matter and be solubilized, to a lesser degree, in runoff water.

Benzene, tetrachloroethene, and PCBs are among the organic contaminants in soil that may enter the atmosphere by volatilization through void space in the soil. Benzene, 4-methylphenol, and tetrachloroethene may also migrate downward to aquifers or be transported to surface water as leachate. The downward migration is aided by percolation of precipitation because these organic contaminants are relatively soluble in water.

Other processes that may affect the distribution of these contaminants in soil are biodegradation and biotransformation. In surface soils and aerobic upper layers of sediment, benzene and 4-methylphenol are the only compounds expected to

biodegrade. In anaerobic sediments or soils, 4-methylphenol will be expected to biodegrade rapidly, and tetrachloroethene may degrade slowly.

All the inorganic contaminants are expected to sorb appreciably onto soils and sediments.

2.3.2 Atmospheric Fate and Transport

Tetrachloroethene and 4-methylphenol entering the atmosphere are expected to be readily degraded and are not expected to persist beyond several days. Benzene and PCBs, however, are expected to persist in the atmosphere. Barium, lead, mercury, and other organics bound to particulate matter that reaches the atmosphere are not expected to degrade but will be removed due to dry deposition and rainfall.

2.3.3 Ground-Water Fate and Transport

Organic contaminants such as benzene, 4-methylphenol, and tetrachloroethene may move into the ground water as leachate from Bowers Landfill percolates down into the saturated zone. These contaminants are then expected to move with the bulk ground-water flow (advection). The quantity of contaminants in the bulk flow is affected by competing processes such as solubility, sorption, bioaccumulation, and volatilization through the soil void space. In general, the higher the solubility of these contaminants, the less likely the contaminant will leave the liquid phase and be sorbed. In many aquifers used for water supply, contaminants such as those discussed are expected to migrate at rates from 10 to nearly 100 percent of the velocity of the ground water (Mackay and others, 1985).

Biodegradation is an important fate process for several contaminants of concern at Bowers Landfill. Benzene is expected to slowly biodegrade in aerobic aquifers, while tetrachloroethene may slowly biodegrade in anaerobic aquifers. 4-methylphenol is expected to biodegrade rapidly under either aerobic or anaerobic environments.

Heavy metals and high molecular weight organics are expected to sorb strongly onto the surface and subsurface soils; however, low concentrations of these contaminants may still reach the saturated zone.

2.3.4 Surface Water Fate and Transport

Surface water may be contaminated through various means. Contaminants in the atmosphere may reach surface water via precipitation. Contaminants in soils and ground water may influence surface water quality as a result of hydraulic connections.

Once in the surface water, volatile contaminants, such as benzene and tetrachloroethene, will volatilize into the atmosphere. PCBs may also volatilize if present in dissolved form. Heavy organic compounds such as PAHs, PCBs, and chlordane will probably precipitate from surface waters and accumulate in sediments and biota. 4-methylphenol present in surface water and sediment is expected to rapidly biodegrade.

Most heavy metals will form complexes with organic and inorganic compounds. All of the heavy metals may bioaccumulate.

CHAPTER 3

EXPOSURE ASSESSMENT

This chapter presents general information on the human and animal populations living near Bowers Landfill, and identifies potential routes of exposure. The chapter also identifies specific human, aquatic, and terrestrial populations that may be exposed to contaminants potentially released from Bowers Landfill. Finally, the chapter discusses the extent to which the identified populations may be potentially exposed to the indicator chemicals via each exposure scenario. The nature and the extent of exposure will determine the potential risks to the identified populations discussed in Chapter 5.

Chapter 1 identified a number of contaminants that were found in samples collected from Bowers Landfill and from nearby off-site areas. While there is not always a direct correlation between contaminants found on the landfill and those found off-site, PRC believes that the available information does not rule out the landfill as a possible contaminant source. Data from the Eckhardt Report (Table 1-1) shows that a wide variety of waste streams were disposed of at Bowers Landfill. Most of the contaminants identified could have been constituents of those waste streams, although data is not available to verify this.

Bowers Landfill may present risks to human health and the environment for several reasons: (1) the site received a large volume of organic and inorganic wastes, (2) standard waste management practices at the landfill consisted of simply dumping the wastes onto the ground, (3) the water table is very shallow, and (4) contamination is present at the surface of the landfill. The discussion on exposure scenarios evaluates present site conditions and discusses the potential for future exposure.

3.1 GENERAL POPULATION INFORMATION

Bowers Landfill is located in a rural area approximately 2 miles north of Circleville, Pickaway County, Ohio. In 1980, the population of Circleville was 12,590 (Dames & Moore, 1987a). Sixty homes are reportedly located within 1 mile of the landfill (Dames & Moore, 1987a). Assuming that each household in Pickaway County

averages 3.9 persons (Dames & Moore, 1987a), about 234 people may live within 1 mile of the site.

PRC could not precisely determine the age characteristics of the persons living within 1 mile of the site based on available information. Instead, PRC reviewed data on general characteristics of rural Ohio counties including Pickaway County. The data indicates that about 7.5 percent of the Pickaway County population is under 5 years of age, while 8.5 percent is at least 65 years of age. Persons in these age ranges are generally considered more sensitive to chemical insults than the general population (U.S. EPA, 1986a). Based on these figures, PRC estimates that 18 people under 5 years of age and 20 people at least 65 years of age may live within 1 mile of the landfill. The percentage of women currently pregnant (another group considered to be more sensitive to chemical insults) could not be estimated. However, PRC does not expect the number of pregnant women living near the site to be very large.

Dames & Moore (1987a) conducted a biological study to identify wildlife populations living near the landfill. Species identified based on sightings or tracks include deer, muskrat, raccoon, opossum, squirrel, woodchuck, and fox. Fish and bird species were not specifically identified except that carp and minnows were seen in the Scioto River adjacent to the site.

3.2 ROUTES OF EXPOSURE AND POTENTIALLY EXPOSED POPULATIONS

PRC identified potential human and environmental exposure scenarios based on a review of available file information and reports, a visual inspection of the landfill, and interviews with persons living in Circleville who have some knowledge of the landfill. These scenarios represent conditions under which persons living near the landfill or wildlife populations that frequent the landfill could be exposed to contaminants. The potential human exposure scenarios include:

- o Ingestion of contaminated ground water
- o Direct contact with or incidental ingestion of contaminated surface water
- o Direct contact with contaminated sediments
- o Ingestion of contaminated fish from the Scioto River

- o Direct contact with or ingestion of contaminated soil
- o Inhalation of contaminated air
- o Ingestion of contaminated crops
- o Ingestion of contaminated terrestrial animals and birds

The potential environmental exposure scenarios include:

- o Direct contact by fish and other aquatic animals with contaminated surface water and sediments
- o Ingestion by terrestrial animals and birds of contaminated plant life

These exposure scenarios are discussed in the following sections.

3.2.1 Ingestion of Contaminated Ground Water

Geologic and hydrogeologic investigations conducted as part of the remedial investigation (Dames & Moore, 1987a) identified both a shallow and deep aquifer beneath the landfill. Dames & Moore suggested that a silty clay layer identified as underlying the shallow aquifer is continuous across the site and, as a result, the two aquifers are not hydraulically connected. However, the data presented in the RI do not fully support this conclusion. Therefore, for the purposes of the endangerment assessment, this report assumes that the two aquifers may be hydraulically connected.

Dames & Moore conducted three rounds of ground-water sampling at Bowers Landfill, one in February 1987, one in April 1987, and one in March 1988. Samples were obtained from wells screened in the shallow aquifer, wells screened in the deeper aquifer, **non responsive**

The RI report (Dames & Moore, 1988) does not indicate which aquifer these private wells use to obtain water. The location of the wells sampled (Figure 1-4) and the sample results are detailed in Chapter 1 (Appendix A presents complete analytical results from both sampling rounds). Of the contaminants of concern, three were identified in the shallow aquifer (tetrachloroethene, barium, and lead) and three were identified in the deeper aquifer (benzene, barium, and lead). However, tetrachloroethene was found only in well W-12, which is upgradient of Bowers

Landfill. Barium was found in residential well samples; these wells are also upgradient of the landfill.

Ground water within the shallow aquifer flows west-southwest from the landfill and discharges into the Scioto River (Dames & Moore, 1987a). Flow direction for the deeper aquifer appears to be similar. However, it is unclear whether ground water within this aquifer discharges to the river. Presently, no public or private water supply wells are located between the landfill and the river. Furthermore, the existing non responsive

As a result, it is unlikely that these wells would be influenced by contaminant releases from the landfill.

The Circleville Water Treatment Plant and Wellfield non responsive
non responsive

Further, any impact is expected to be minimal at most because of the distance between the wellfield and the landfill. The Circleville Water Department stated that none of the contaminants of concern identified at Bowers Landfill have been detected in water samples from these wells (Jones, 1987).

Analysis of samples of the City of Circleville's water supply, as well as consideration of the fate and transport properties of the indicator contaminants, provides further evidence of the expected minimal impact of releases from the landfill on the well field and subsequently the city's water supply. Concentrations of indicator chemicals measured in water quality samples for the City of Circleville Department of Public Utilities Water Supply System between 1980 and 1987 are summarized in Table 3-1. Sampling points included raw water supply sources (wells No. 1, 2, and 3) and various commercial and private distribution points. The only indicator chemicals measured above detection limits (on a single occasion) are barium (160 ug/L) and lead (1 ug/L). Both these concentrations are well below the acceptable drinking water standards for barium (1,000 ug/L) and lead (50 ug/L, respectively.

Of the remaining indicator chemicals, tetrachloroethene and benzene would be expected to move with the ground-water flow (see Chapter 2). However,

TABLE 3-1
SUMMARY OF WATER QUALITY SAMPLING RESULTS
FOR THE CITY OF CIRCLEVILLE
DEPARTMENT OF PUBLIC UTILITIES
WATER SUPPLY SYSTEM, 1980 - 1987
CONCENTRATIONS (ug/L) OF INDICATOR CHEMICALS DETECTED

Location:	non responsive					
Date:	08/24/87	06/19/86	06/19/86	06/19/86	12/05/85	04/27/83
<u>Compound</u>						
Barium	160	<300	<300	<300	<300	--
Lead	1	ND	<5	<5	<5	--
Mercury	<0.2	<0.5	<0.5	<0.5	<0.5	--
Chlordane	--	--	--	--	--	ND
PCBs	--	--	--	--	--	ND
Tetrachloro-ethene ^b	--	--	--	--	--	<0.5
PAHs	--	--	--	--	--	ND

Notes:

Adopted from: Ohio Department of Health, 1980-1987.

- ^a Only the results for samples that were analyzed for at least 1 indicator chemical other than tetrachloroethene are presented; see footnote b.
- ^b 34 additional samples within this time period were analyzed for tetrachloroethene; all the results were negative.

tetrachloroethene was never measured above the detection limit (35 samples) in any samples from the City of Circleville water supply system. Though benzene was never specifically analyzed for, it is unlikely to have migrated from the landfill to the Circleville Water Treatment Plant and well field, based on the results for tetrachloroethene. Chlordane, PCBs, and PAHs were analyzed for in a single water quality sample (Table 3-1) but were not detected. Furthermore, these compounds are likely to adsorb to soils and are unlikely to migrate with ground water; they were not detected in any ground-water samples collected near the landfill.

The Sturm and Dillard Company operates a quarry approximately 1/2 mile south of Bowers Landfill, between Island Road and the Scioto River. The quarry is located between the landfill and the Circleville wellfield; however, quarrying operations are not expected to affect ground-water movement in the direction of the wellfield. Sturm and Dillard currently pumps approximately 108,000 gallons of water per week from a pond south of Bowers Landfill. This water is used for gravel washing. After use, approximately half of the water is returned to the pond and half is discharged to a second pond further south (Fissel, 1987). Both ponds are in contact with ground water. Under Sturm and Dillard's current operations, there is no net inflow or outflow relative to the two ponds and the ground-water system. Thus, there should be little effect on ground-water flow.

In the future, wells could be placed in the shallow or deep aquifers between the landfill and the river. PRC considers this unlikely, since the area between the landfill and the river is regularly flooded (see Section 3.2.2). However, if such wells were installed, persons using the wells for water supply would form the population of concern under this scenario.

3.2.2 Direct Contact with or Incidental Ingestion of Contaminated Surface Water

The Scioto River may be impacted by the landfill via one of the following three routes. First, as stated in Section 3.1, ground water from the shallow aquifer beneath the site apparently discharges to the Scioto River west of the landfill. Second, potentially contaminated surface runoff or leachate from the landfill generally flows to the west and south toward the river. Some of the runoff is collected in two ditches that run along the west and east sides of the landfill. Water from the east ditch is directed into the Scioto River (CH2M Hill, 1983).

Finally, the cultivated field west of the landfill is flooded approximately 29 days per year (CH2M Hill, 1983). This field was flooded twice, for extended periods of time,, during the 8-month remedial investigation of Bowers Landfill. Based on flood stage data presented in the RI report (Dames & Moore, 1987a), parts of the landfill may be flooded as often as every 2 years. Flooding may result in the leaching of contaminants or transport of contaminated soils from the landfill to the river.

Surface water samples were collected from the Scioto River, from drainage ditches along the east and west sides of the landfill, and from one of the quarries east of the landfill. The quarry and the east ditch are hydraulically connected to each other and to ground water. Thus, these surface water bodies could be affected by ground-water discharge. The samples show that a number of inorganic and organic compounds were measured in the river and drainage ditches. Five of the nine indicator chemicals, were detected in the Scioto River including tetrachloroethene, PCBs, barium, lead, and mercury. However, PCBs were found only in a sample collected upstream of the landfill. Four indicator chemicals including PCBs, barium, lead, and mercury were detected in the east drainage ditch.

The Scioto River is reportedly used for fishing and boating (Dames & Moore, 1987a). Persons engaged in these activities may enter the river and come into direct contact with the water. Incidental ingestion of river water may also occur, but the potential is probably much less than for direct contact. Access to the drainage ditch is not restricted, and persons may accidentally fall into the ditch, enter the ditches (to play or explore, for example), or consume water from the ditch. Although the probability of these activities occurring is low, they still must be considered.

Another potential exposure pathway to water from the Scioto River is via the use of river water for irrigation or livestock watering. PRC contacted the U.S. Soil Conservation Service to investigate this possibility. Mr. Mark Scarpitti of the Soil Conservation Service, Pickaway County Office, stated that he knew of no such uses of water from the Scioto River near Bowers Landfill (Scarpitti, 1987).

3.2.3 Direct Contact with Contaminated Sediment

Sediments in the Scioto River may be impacted by the landfill via any of the three routes identified in Section 3.2.2. Sampling efforts conducted in February and April 1987 as part of the remedial investigation (Dames and Moore, 1987a) revealed the presence of a number of inorganic and organic contaminants in the sediments of the Scioto River (both upstream and downstream of the landfill) and drainage ditches adjacent to the landfill. The results are presented in Appendix A. Six of the 9 indicator chemicals were found in river sediments, including chlordane, 4-methylphenol, PAHs, barium, lead, and mercury. These six indicator chemicals, in addition to PCBs, were also found in sediments from drainage ditches. It should be noted, however, that chlordane was detected only in February 1987 samples.

As discussed in the previous section, the Scioto River is used for boating and fishing. Persons most likely to be exposed to contaminated river sediments are those persons who may fish or walk along the banks of the river and, as a result of these activities, come into direct contact with sediments. Direct contact with ditch sediments would most likely involve persons who accidentally fall into the ditch or persons (probably children) who might explore or play in the ditch. Contact with ditch sediments is not expected to be frequent.

3.2.4 Ingestion of Contaminated Aquatic Animals from the Scioto River

As stated earlier, tetrachloroethene, PCBs, barium, lead, and mercury have been measured in Scioto River water, while chlordane, 4-methylphenol, PAHs, barium, lead, and mercury have been measured in river sediments. Fish and other aquatic animals may be exposed to these chemicals through direct contact with or ingestion of river water and sediment. Such exposure, in turn, may result in elevated levels of some of these chemicals through bioconcentration (see Chapter 2). Of the contaminants identified in the Scioto River water and sediment, exposure to PCBs, PAHs, chlordane, and mercury will most likely result in elevated tissue levels based on the high bioconcentration factors for these chemicals (U.S. EPA, 1986a). Persons ingesting fish or other aquatic animals caught from the river may be exposed to those contaminants that concentrate in edible tissues.

3.2.5 Direct Contact with or Ingestion of Contaminated Soil

Soil samples were collected from Bowers Landfill, adjacent agricultural areas, and off-site background areas in September 1986 and in March 1988. The analytical results of these samples (including both grab samples and Shelby Tube samples) revealed the presence of six indicator chemicals: chlordane, PAHs, PCBs, barium, lead, and mercury. All six chemicals were found both in samples collected from the landfill and in samples collected from the agricultural field west of the landfill. For two of the chemicals, PAHs and PCBs, maximum concentrations found on the landfill were much higher than maximum concentrations in adjacent areas. Four indicator chemicals, barium, lead, mercury, and PAHs were also found in off-site background samples.

Access to the site is unrestricted, and no fence surrounds the site. An estimated 234 people live within 1 mile of the landfill (both east and west of the Scioto River); any of these persons gaining access to the site may be exposed to contaminated soils. PRC assumes that adults will be exposed almost exclusively via direct contact with soils. Such direct contact may result from activities such as hiking, hunting, and farming (land adjacent to the landfill is occasionally farmed (Dames & Moore, 1987a)). Children may also have direct contact with contaminated soils as a result of exploration or play activities at the landfill. In addition, young children (ages 2 to 6) may ingest contaminated soils (U.S. EPA, 1986c). Pica behavior (the desire to eat unnatural foods, including soil) among children of this age is well-known. Based on census data, PRC estimated that approximately 18 children under the age of 5 years, may live within 1 mile of the landfill.

3.2.6 Inhalation of Contaminated Air

No air sampling has been conducted at Bowers Landfill, however, the results of limited air monitoring with survey instruments during the remedial investigation, revealed no ambient contamination (Dames & Moore, 1988). Nonetheless, the extent of air contamination at the Bowers Landfill (in the form of volatilized organics and contaminated dust particles) is not presently known.

Soil at Bowers Landfill is contaminated with six indicator chemicals: chlordane, PAHs, PCBs, barium, lead, and mercury. The air above Bowers Landfill

and adjacent areas may become contaminated through the volatilization of organic contaminants from site soils and from adjacent areas (contaminated as a result of transport to off-site areas). For example, significant concentrations of PCBs may volatilize from contaminated soils (U.S. EPA, 1986c). In addition, persons may also be exposed to escaping methane generated as a result of decomposed household waste disposed of at the landfill. Methane could act as a carrier for other volatile organic compounds. Persons gaining access to the site or adjacent lands could be exposed to these volatilized contaminants.

In addition to the volatilization of organic soil contaminants, soil particles to which contaminants have adsorbed may become airborne as a result of wind erosion or plowing (land adjacent to the landfill is farmed). Particles could also become locally airborne as a result of persons exploring or playing at the site. Persons gaining access to the site or adjacent lands could be exposed to these contaminated soil particles.

3.2.7 Ingestion of Contaminated Crops

Land west and north of Bowers Landfill is reportedly cultivated to grow soybeans (Dames & Moore, 1987a). Sampling of the soils west of the landfill showed the presence of chlordane, PAHs, PCBs, barium, lead, and mercury. Cultivated lands north of the site may become contaminated due to contaminant transport (via flooding or soil erosion) from the landfill.

Crops grown in contaminated soils can also become contaminated through the following pathways: (1) through the root system via soil migration, (2) through the vascular system of the plant, and (3) through the fluid transport system of the plants (Dames & Moore, 1987a). Of the indicator chemicals identified in soils west of the landfill, PRC expects that PCBs, barium, and lead have the greatest potential for uptake into plants (Pal and others, 1980).

No studies have been conducted regarding the actual contamination of crops grown on lands west and north of the landfill. However, the potential exists for these crops to become contaminated; persons ingesting these crops could, in turn, become exposed. The number of persons exposed via this scenario may be larger

than the approximately 234 persons living within 1 mile of the landfill and may include persons living some distance from the site.

3.2.8 Ingestion of Contaminated Terrestrial Animals and Birds

Dames & Moore (1987a) conducted a biological study to collect information on wildlife species present in the vicinity of Bowers Landfill. Terrestrial species identified in the vicinity of the landfill include deer, muskrat, raccoon, opossum, squirrel, woodchuck, and fox. Avian species (including waterfowl) in the vicinity of the site were not specifically identified. However, such species may be found in the vicinity of the landfill.

Terrestrial animals may be exposed to site contaminants, including chlordane, PAHs, PCBs, barium, lead, and mercury (identified in soils on and near the landfill) via consumption of plant life in the vicinity of the landfill. The plants may have become contaminated through uptake of soil contaminants or deposition of contaminated dust. Species such as the fox may be exposed by ingesting other contaminated animals such as squirrels, rabbits, or small rodents. In turn, persons who hunt any of these terrestrial animals near the landfill may be exposed through consuming contaminated animal tissue.

Waterfowl that frequent the land or portions of the Scioto River near Bowers Landfill may ingest contaminated plant life near the river. In turn, these birds may be hunted and consumed, thereby exposing humans (primarily hunters and their families) to contamination.

3.2.9 Direct Contact with or Ingestion of Contaminated Surface Water and Sediments by Aquatic Life

As stated in Sections 3.2.2 and 3.2.3, five of the Indicator chemicals (tetrachloroethene, PCBs, barium, lead, and mercury) have been identified in the Scioto River; six indicator chemicals have been found in Scioto River sediments (chlordane, 4-methylphenol, PAHs, barium, lead, and mercury). Fish or other aquatic animals may become exposed to the contaminants via either direct contact or ingestion. Furthermore, levels of some of these compounds, specifically PCBs, chlordane, PAHs, and mercury, may bioconcentrate within the tissues of aquatic

species over time. As a result, contaminant levels that may be acceptable in the short term may increase to toxic levels in the long term.

Dames & Moore (1987a) reported that carp and minnows were observed in the Scioto River and that fishing occurred in the river adjacent to the landfill. This indicates that species of game fish probably live in the Scioto River.

According to the RI report (Dames & Moore, 1987a), several aquatic species listed by the U.S. Fish and Wildlife Service as endangered or threatened could inhabit the vicinity of Bowers Landfill, although none have been directly observed. These species include:

- o Fish: Scioto madtom
- o Clams: Pearly mussel, Cumberland bean pearly mussel, orange-footed pearly mussel, white cat's paw, and fat pocketbook

The Ohio Department of Natural Resources maintains a list of "species of concern," a less serious category than threatened. Although no species of concern have been reported near the site, several known habitats farther from the site could be adversely affected by effluent from Bowers Landfill. One area in the Scioto River, about 1 mile south of the site, is inhabited by the following aquatic species: river redhorse, false map turtle, silver chub, streamline chub, and goldeneye. Farther south, below the junction of the river with Big Darby Creek, the rigid pocketbook and northern riffle shell bivalve have been seen. The bluebreast darter exists in the section of the Scioto River passing through the built-up area of Circleville. Other species of concern, including the lake chubsucker, have been reported in a backwater several miles farther south. Still more species of concern have been reported upstream of the site. Additional information on these species is included in the Dames & Moore (1987a) RI report.

3.2.10 Ingestion by Terrestrial Animals and Birds of Contaminated Plant Life

As discussed in Section 3.2.7, plant life at or near the landfill may become contaminated through the uptake of contaminants from the soil or by the deposition of contaminated soil particles on exposed surfaces. In addition,

macrophytes (macroscopic types of plant life) in the Scioto River may become contaminated from exposure to contaminated surface water.

Members of the terrestrial animal populations living at or near Bowers Landfill may consume contaminated plant life as they forage for food. Likewise, waterfowl may consume contaminated macrophytes from the Scioto River. The number and species of animals and waterfowl that may be exposed via this scenario could not be precisely determined based on the available information.

Several avian species listed by the U.S. Fish and Wildlife Service as endangered or threatened could exist near Bowers Landfill and prey on site inhabitants (Dames & Moore, 1987a). These include the bald eagle, peregrine falcon, gray bat, Indiana bat, and Virginia big-eared bat. However, there is no suitable habitat for these species in the immediate vicinity of the site.

3.3 EXTENT OF EXPOSURE

This section of the endangerment assessment discusses the extent to which human and animal populations may be exposed to the indicator chemicals under each of the exposure scenarios. In most cases, our discussion is qualitative in nature rather than quantitative for two reasons. First, it is difficult to estimate representative exposure conditions for each scenario. For example, insufficient information is available to quantify the frequency and duration that humans or animals may be exposed via each scenario. Estimates can be made, but in most instances, precise information is unavailable. Second, when frequency and duration information are available, additional factors required to estimate the extent of exposure via specific scenarios have not been developed. For these reasons, any quantifications may not resemble actual conditions.

For exposure scenarios where PRC was able to calculate a quantitative exposure estimate, we used geometric mean concentrations to represent probable case conditions and maximum concentrations to represent worst case conditions. PRC calculated geometric means, rather than arithmetic means, because the geometric mean places less weight on extreme values. This is appropriate when contaminants are detected in only a few of the many samples collected, as was the case for some of the indicator chemicals at Bowers Landfill. The geometric mean

concentration provides a more realistic description of "average" exposures under these conditions. Thus, it is useful in evaluating probable case exposure conditions. By also evaluating exposure to maximum concentrations, worst case conditions can be represented. Appendix D outlines the methods that PRC used to calculate geometric mean concentrations.

To calculate exposure doses for noncarcinogenic indicator chemicals in different environmental media, PRC used the following equation:

$$\begin{array}{ccccccc} \text{Body Dose} & & \text{Concentration} & & \text{Amount of} & & \% \text{ Absorbed} \\ \text{Level} & = & \text{in Medium} & \times & \text{Medium Ingested} & \times & \text{(varies for} \\ \text{(mg/kg/day)} & & \text{(mg/kg)} & & \text{(kg/day)} & & \text{contaminant} \\ & & & & & & \text{and exposure} \\ & & & & & & \text{route)} \\ & & & & & & \times \frac{1}{\text{Body weight (3-1)}} \\ & & & & & & \text{(kg)} \end{array} \quad (3-1)$$

To calculate exposure doses for carcinogenic indicator chemicals, PRC calculated an average daily dose over a 70-year lifetime. The average daily dose can be determined from the following equation:

$$\begin{array}{ccccccc} \text{Daily Dose} & & \text{Body Dose} & & \text{Frequency of Contact} & & \text{Years of Exposure} \\ \text{Over Lifetime} & = & \text{Level from} & \times & \text{365 Days} & \times & \text{70-Year Lifetime} \\ \text{(mg/kg/day)} & & \text{Equation 3-1} & & & & \\ & & \text{(mg/kg/day)} & & & & \end{array} \quad (3-2)$$

The specific assumptions used in making these calculations are explained in the exposure scenarios that follow.

3.3.1 Ingestion of Contaminated Ground Water

As stated earlier, the shallow ground water at the site flows west-southwest from the landfill and discharges into the Scioto River (Dames and Moore, 1988); Ground water in the deep aquifer also flows to the west, but may not discharge to the river. Contamination has been identified in both aquifers, and PRC has assumed that the aquifers are hydraulically connected. However, at present, no public or private drinking water wells are located between the site and river. Table 3-2 presents a list of ground-water monitoring wells upgradient and downgradient at Bowers Landfill as well as nearby residential wells (also upgradient) that were sampled during the remedial investigation.

TABLE 3-2
MONITORING WELLS AND RESIDENTIAL WELLS
SAMPLED DURING THE REMEDIAL INVESTIGATION

Upgradient Wells¹:	W-4	P-4A	W-9
	W-12	P-12B	W-13
	P-13B		
Downgradient Wells¹:	W-5	P-5A	P-5B
	W-6	P-6A	P-6B
	W-7	P-7A	W-8
	P-8A	P-8B	W-10
	W-11		
Residential Wells²:	non responsive		

Notes:

- ¹ Upgradient and downgradient wells were determined by comparing well locations (Figure 1-4) with potentiometric maps for the shallow and deep aquifers (Figures 2-2 and 2-3).
 - ² All residential wells sampled are upgradient of the landfill.
-

PRC estimated the potential exposure associated with the ingestion of contaminated ground water using both the probable case (geometric mean) and the worst case (maximum concentration) levels from wells located downgradient of the landfill. Although no one currently uses the aquifer at this location as a drinking water source, these data represent potential future exposure concentrations. Frequent of detection and concentrations (geometric mean and maximum) of indicator chemicals measured in upgradient wells, downgradient wells, and residential wells near Bowers Landfill are presented in Table 3-3.

Table 3-4 shows the estimated exposure doses for ground-water ingestion. PRC calculated exposure doses only for those indicator chemicals which had higher concentrations in downgradient wells than upgradient wells. Although tetrachloroethene was found in ground water, it was detected only in a single upgradient well, W-12. Lead concentrations (both geometric mean and maximum) were nearly identical for upgradient and downgradient wells. Because it is unlikely that Bowers Landfill is the source of these chemicals in ground water, PRC did not calculate exposure doses.

PRC calculated body dose levels by assuming that adults weighing 70 kg would consume 2 liters of ground water per day. PRC also assumed 100 percent absorption. [Note: Risks posed by these estimated exposure doses are characterized using factors developed based on experimental animal data (see Chapter 5). These factors are derived from results of animal dose-response studies, extrapolated to represent human dose-response relationships. The extrapolations do not attempt to address any potential differences between animal and human absorption of a particular compound. Therefore, the use of a 100 percent absorption factor does not represent an assumption that all contaminants in the water will be absorbed by the body, but rather the assumption that the human body will absorb the contaminants to the same extent as the experimental animals.] For carcinogens (benzene), PRC calculated average daily doses over a lifetime. We assumed conservatively that persons ingesting ground water would be exposed for 365 days per year over a 70-year lifetime. Under these conditions of continuous exposure, the average daily dose over a lifetime is equal to the body dose level calculated by Equation 3-1.

TABLE 3-3
FREQUENCIES OF DETECTION AND CONCENTRATIONS OF INDICATOR CHEMICALS
MEASURED IN GROUND WATER NEAR BOWERS LANDFILL

Compound	Upgradient Wells				Downgradient Wells				Residential Wells			
	Adjusted Frequency of Detection ¹	Adjusted Frequency of Detection ²	Geometric Mean (ug/L)	Maximum Concentration (ug/L)	Adjusted Frequency of Detection	Adjusted Frequency of Detection	Geometric Mean (ug/L)	Maximum Concentration (ug/L)	Adjusted Frequency of Detection	Adjusted Frequency of Detection	Geometric Mean (ug/L)	Maximum Concentration (ug/L)
Barium	16/16	16/16	185	368	37/37	37/37	330	2070	5/5	5/5	112	[130]
Lead	2/16	1/15	1.2	7.0	8/37	1/27	1.2	6.9	0/5	--	--	--
Mercury	2/16	0/16	--	--	0/37	--	--	--	0/5	--	--	--
Benzene	0/16	--	--	--	3/37	3/37	0.70	6.0	0/5	--	--	--
Tetrachloroethene	3/16	3/16	0.89	5.3	0/37	--	--	--	0/5	--	--	--
Chlordane	0/16	--	--	--	0/37	--	--	--	0/5	--	--	--
PCBs	0/16	--	--	--	0/37	--	--	--	0/5	--	--	--
4-Methyl Phenol	0/16	--	--	--	0/37	--	--	--	0/5	--	--	--
PAHs	0/16	--	--	--	0/37	--	--	--	0/5	--	--	--

Notes:

[] Estimated value (see Appendix A)

-- Not calculated

1 Frequency of detection is defined as a/b, where --

a = number of times a compound was detected

b = total number of samples

Sample results which were identified by the laboratory as due to blank contamination are not counted in either a or b.

2 Adjusted frequency of detection omits samples from which results were questionable due to other QA/QC problems; only samples included in this column were used to determine geometric mean and maximum concentrations.

TABLE 3-4
ESTIMATED DOSES VIA INGESTION OF
CONTAMINATED GROUND WATER AT BOWERS LANDFILL

Compound ¹	Mean Concentration ² (ug/L)	Maximum ² Concentration ² (ug/L)	Daily Dose ³		Average Lifetime Dose ⁴	
			Probable Case (mg/kg/day)	Realistic Worst Case (mg/kg/day)	Probable Case (mg/kg/day)	Worst Case (mg/kg/day)
Inorganic-						
Barium	330	2070	9.43 E-03	6.91 E-02	NA	NA
Organic-						
Benzene	0.70	6.0	--	--	2.00 E-05	1.71 E-04

Notes:

NA Not applicable.

-- Not calculated

1 Only results for indicator chemicals that were detected in higher concentrations in downgradient ground-water monitoring wells are presented.

2 Includes samples from downgradient ground-water monitoring wells; see Table 3-2.

3 Daily doses were calculated using Equation 3-1, the geometric mean and maximum concentrations observed in the downgradient ground-water monitoring wells, and the following assumptions:

Amount ingested	=	2 liters
% absorbed	=	100
Body weight	=	70 kg

4 Average lifetime doses were calculated using Equation 3-2, the geometric mean and maximum concentrations observed in the downgradient ground-water monitoring wells, and the following assumptions:

Frequency of contact	=	365 days
Years of exposure	=	70 years

The exposure estimates in Table 3-4 must be evaluated cautiously for several reasons. First, the geometric mean concentrations for benzene is calculated based on an adjusted detection frequency of 3/37; in other words, benzene was detected in only 3 of the 37 samples. Second, the average lifetime doses for benzene also assume continuous exposure over a 70-year period. It is unlikely that such exposure would occur.

PRC also did not evaluate exposure to indicator chemicals (barium) found in residential wells, since these wells are also upgradient of the landfill. Two of the four residential wells had arsenic concentrations slightly higher than the maximum downgradient concentration.

3.3.2 Direct Contact with or Incidental Ingestion of Contaminated Surface Water

Two discrete surface water units exist at the site. The first is the Scioto River, which may be impacted through ground-water discharge, surface runoff, and flooding of the landfill. The second unit is composed of the drainage ditches and quarry adjacent to the site. Table 3-5 presents a list of surface water and sediment sampling locations near Bowers Landfill.

Table 3-6 presents the frequencies of detection and geometric mean and maximum concentrations of indicator chemicals found in the Scioto River (upstream and downstream of the landfill) and the drainage ditches. As stated in Section 3.2.2, exposure to contaminated surface water would be through incidental ingestion and direct contact due to accidental falls into the Scioto River or drainage ditches.

PRC did not calculate exposure doses for direct contact for two reasons. First, because of the incidental nature of this exposure, it would be difficult to develop realistic values for the amount of water contacted and the frequency of exposure. Second, few organic compounds were found in surface water; metals in surface water are not likely to be absorbed through the skin. PRC also did not calculate exposure doses for incidental ingestion of surface water. However, Table 3-6 presents the probable case (geometric mean) and worst case (maximum) concentrations in surface water that may be accidentally ingested.

TABLE 3-5
SURFACE WATER AND SEDIMENT SAMPLING LOCATIONS
NEAR BOWERS LANDFILL

Drainage ditches and quarry ¹ :	SW-21	SW-27
	SW-24	SW-28
	SW-25	SW-29
	SW-26	
Scioto River - Upstream:	SW-18	
Scioto River - Downstream:	SW-19	SW-22
	SW-20	SW-23

Notes:

- ¹ SW-25 is located in the quarry east of the landfill; SW-28 is located in the drainage ditch west of the landfill. All other locations are in the drainage ditch east of the landfill (see Figure 1-5).
-

TABLE 3-6
FREQUENCIES OF DETECTION AND CONCENTRATIONS
OF INDICATOR CHEMICALS MEASURED IN SURFACE WATERS
OF THE SCIOTO RIVER AND DRAINAGE DITCHES AT BOWERS LANDFILL

Compound	Scioto River - Upstream				Scioto River - Downstream				Drainage Ditches			
	Frequency of Detection	Adjusted Frequency of Detection ¹	Geometric Mean (ug/L)	Maximum Concentration (ug/L)	Frequency of Detection	Adjusted Frequency of Detection	Geometric Mean (ug/L)	Maximum Concentration (ug/L)	Frequency of Detection	Adjusted Frequency of Detection	Geometric Mean (ug/L)	Maximum Concentration (ug/L)
Barium	2/2	2/2	56	[60]	9/9	9/9	54	[60]	19/19	19/19	101	[199]
Lead	1/2	0/1	--	--	4/9	0/5	--	--	4/19	1/15	1.3	8.65
Mercury	0/2	--	--	--	2/9	1/3	0.13	0.20	1/19	1/5	0.12	0.27
Benzene	0/2	--	--	--	0/9	--	--	--	0/19	--	--	--
Tetrachloroethene	1/2	1/2	0.74	1.1 J	2/9	2/9	0.59	1.1 J	0/19	--	--	--
Chlordane	0/2	--	--	--	0/9	--	--	--	0/19	--	--	--
PCBs	1/2	1/2	0.77	1.2	0/9	--	--	--	1/19	1/19	0.55	2.6
4-Methyl Phenol	0/2	--	--	--	0/9	--	--	--	0/19	--	--	--
PAHs	0/2	--	--	--	0/9	--	--	--	0/19	--	--	--

Notes:

[J], J Estimated value (see Appendix A)

-- Not calculated

1 Frequency of detection is defined as a/b, where --
a = number of times ϕ compound was detected
b = total number of samples

Sample results which were identified by the laboratory as due to blank contamination are not counted in either a or b.

2 Adjusted frequency of detection omits samples from which results were questionable due to other QA/QC problems; only samples included in this column were used to determine geometric mean and maximum concentrations.

3.3.3 Direct Contact with Contaminated Sediment

As with the surface water, sediments can be divided into two discrete units; Scioto River sediments and drainage ditch sediments. Table 3-7 presents the geometric mean and maximum sediment concentrations in both units. PRC did not attempt to calculate estimated exposure dosages for this scenario due to the incidental exposure expected and the number of assumptions that would have to be made.

3.3.4 Ingestion of Contaminated Aquatic Animals

As stated earlier, the potential exists for aquatic animals living in the Scioto River to bioaccumulate or bioconcentrate contaminants in river water or sediments. However, tissue samples have not been taken from aquatic life in the Scioto River to determine the degree of exposure. The contaminants of most concern are PCBs, chlordane, PAHs, and mercury. Surface water samples taken from the Scioto River showed no significant increase in these contaminants between upstream and downstream samples. Therefore, PRC did not calculate potential contaminant body burdens of the aquatic animals.

3.3.5 Direct Contact with or Ingestion of Contaminated Soils

The potential exists for exposure to contaminated soils at the site and adjacent to the site through the following routes: adults farming, hiking, or hunting, and children playing at or near Bowers Landfill. Children represent the most sensitive group. Therefore, PRC has focused this exposure scenario on children exposed to contaminated soils. Table 3-8 presents a list of soil sampling locations at or near Bowers Landfill.

U.S. EPA (1986c) describes the ingestion of soils as occurring predominantly in children aged 2 to 6. Some of this ingestion will be incidental (playing or eating with dirty hands), while some will involve children who exhibit pica behavior (the desire to eat unnatural foods, including soil).

TABLE 3-7
FREQUENCIES OF DETECTION AND CONCENTRATIONS OF INDICATOR CHEMICALS
MEASURED IN SEDIMENTS OF THE SCIOTO RIVER AND DRAINAGE DITCHES AT BOWERS LANDFILL

Compound	SCIOTO RIVER				DRAINAGE DITCHES			
	Upstream		Downstream		Adjusted		Frequency of	
	Frequency of Detection ¹	Frequency of Detection ²	Geometric Mean (mg/kg)	Maximum Concentration (mg/kg)	Frequency of Detection	Frequency of Detection	Geometric Mean (mg/kg)	Maximum Concentration (mg/kg)
Barium	2/2	2/2	113	118	9/9	9/9	106	312
Lead	2/2	2/2	31	38	9/9	8/8	34	39
Mercury	2/2	1/1	--	0.40	9/9	4/4	0.48	0.59
Chlordane	0/2	--	--	--	2/9	2/9	67	200
PCBs	0/2	--	--	--	0/9	--	--	--
Benzene	0/2	--	--	--	0/9	--	--	--
Tetrachloroethene	0/2	--	--	--	0/9	--	--	--
4-Methylphenol	0/2	--	--	--	1/9	1/9	0.036	0.670
PAHs								
Benzo(a)Anthracene	2/2	2/2	0.415	0.420 J	8/9	8/9	0.256	3.600
Benzo(a)Pyrene	2/2	2/2	0.408	0.450 J	9/9	9/9	0.217	0.370 J
Benzo(b)Fluoranthene	2/2	2/2	0.900	0.910	9/9	9/9	0.451	0.750
Chrysene	2/2	2/2	0.519	0.550	9/9	9/9	0.287	0.480
Dibenzo(a,h)anthracene	2/2	2/2	0.116	0.160 J	1/9	1/9	0.030	0.130 J
Indeno(1,2,3-cd)pyrene	2/2	2/2	0.275 J	0.290 J	5/9	5/9	0.064	0.250 J

Notes:

E, J Estimated value (see Appendix A)

-- Not calculated

1 Frequency of detection is defined as a/b, where --

a = number of times a compound was detected

b = total number of samples

Sample results which were identified by the laboratory as due to blank contamination are not counted in either a or b.

2 Adjusted frequency of detection omits samples from which results were questionable due to other QA/QC problems; only samples included in this column were used to determine geometric mean and maximum concentrations.

TABLE 3-8
SOIL SAMPLING LOCATIONS
AT OR NEAR BOWERS LANDFILL

Background (West of Scioto River) ¹ :	SO-45	SO-51	SO-53
	SO-46		
On or Adjacent to Landfill ¹ :	SO-30	SO-35	SO-40
	SO-31	SO-36	SO-41
	SO-32	SO-37	SO-44
	SO-33	SO-38	SO-47
	SO-34	SO-39	SO-48
Agricultural Areas West and North of Landfill ¹ :	SO-5	SO-10	SO-43
	SO-6	SO-11	SO-49
	SO-7	SO-42	SO-50

Note:

¹ Sampling locations are shown on Figure 1-6

U.S. EPA (1986c) describes an investigation of excessive lead accumulation in children 2 to 6 years of age. The study (Lepow, 1975; reported in U.S. EPA, 1986c) reported that the total average soil ingestion for a 2-year-old child is 0.6 g/day. In contrast, a study by Kimbrough and others (1984) for the Centers for Disease Control estimated the average soil ingestion rate for children between 0 and 5 years of age. The average soil ingestion rate for children 3.5 to 5 years of age was estimated at 1 g/day, while the rate for a child of 5 was 0.1 g/day. Based on these reports and the assumption that only children aged 4 through 6 would gain entry to the Bowers site and ingest on-site soils, we chose the value of 0.1 g/day as an average or "most-probable" ingestion rate. PRC selected 1.0 g/day to represent a worst case exposure.

PRC estimated potential exposures due to ingestion of soil using probable case (geometric mean concentration) and worst case (maximum concentration) contaminant levels in soil on or adjacent to the landfill. Table 3-9 presents frequencies of detection, as well as geometric mean and maximum soil concentrations of the indicator chemicals for background locations, locations on or adjacent to the landfill, and agricultural areas.

PRC calculated exposure estimates only for indicator chemicals found on or adjacent to the landfill at concentrations higher than background. These chemicals include barium, lead, mercury, chlordane, PCBs, and PAHs. For the first four chemicals, both geometric mean and maximum landfill concentrations were above background, so probable case and worst case estimates were calculated. For PAHs, maximum concentrations on the landfill were above background areas. Thus, only a worst case exposure estimate was calculated for PAHs.

Table 3-10 shows the estimated exposure doses for ingestion of contaminated soil. PRC used Equation 3-1 to calculate body dose levels by assuming that children weighing 20 kg would consume either 0.1 g/day (most probable case) or 1.0 g/day (worst case) of soil. We also assumed 50 percent absorption. [Note: 50 percent absorption was selected to represent the expected decreased bioavailability of contaminants adsorbed to soils in comparison to the bioavailability of contaminants supplied in drinking water or in food to experimental animals. Therefore, the use of a 50 percent absorption factor does not represent an assumption that 50 percent of the contaminants are absorbed by the body, but rather the assumption that the

TABLE 3-9
FREQUENCIES OF DETECTION AND CONCENTRATIONS OF INDICATOR CHEMICALS
MEASURED IN SOILS AT BACKGROUND LOCATIONS
AND AT LOCATIONS ON OR ADJACENT TO BOWERS LANDFILL

Compound	Background Locations				Locations On or Adjacent to the Landfill				Agricultural Areas			
	Adjusted Frequency of Detection	Adjusted Frequency of Detection	Geometric Mean (mg/kg)	Maximum Concentration (mg/kg)	Adjusted Frequency of Detection	Adjusted Frequency of Detection	Geometric Mean (mg/kg)	Maximum Concentration (mg/kg)	Adjusted Frequency of Detection	Adjusted Frequency of Detection	Geometric Mean (mg/kg)	Maximum Concentration (mg/kg)
Barium	2/2	2/2	152	156	15/15	15/15	189	279	7/7	7/7	121	198
Lead	5/5	5/5	47	74 E	21/21	21/21	78	179	11/11	11/11	59	102 E
Mercury	2/2	0/2	--	--	15/15	15/15	0.27	0.43	7/7	2/2	0.48	0.58
Chlordane	0/2	--	--	--	2/15	2/15	0.015	0.210	1/7	1/7	0.014	0.110
PCBs	0/2	--	--	--	9/15	9/15	0.238	3.600	1/7	1/7	0.063	0.240
Benzene	0/2	--	--	--	0/15	--	--	--	0/7	--	--	--
Tetrachloroethene	0/2	--	--	--	0/15	--	--	--	0/7	--	--	--
4-Methyl Phenol	0/2	--	--	--	0/15	--	--	--	0/7	--	--	--
PAHs												
Benzo(a)Anthracene	2/2	2/2	0.130	0.140 J	14/15	14/15	0.116	4.300	6/7	6/7	0.081	0.210 J
Benzo(a)Pyrene	2/2	2/2	0.134	0.150 J	12/15	12/15	0.115	4.300	5/7	5/7	0.088	0.230 J
Benzo(b)Fluoranthene	2/2	2/2	0.265	0.280 J	11/14	11/14	0.178	8.600	7/7	7/7	0.204	0.510
Chrysene	2/2	2/2	0.160	0.160 J	14/15	14/15	0.169	5.200	7/7	7/7	0.136	0.240 J
Dibenzo(a,h) anthracene	0/2	--	--	--	1/15	1/15	0.026	0.960 J	0/7	--	--	--
Indeno(1,2,3-cd) pyrene	1/2	1/2	0.047	0.110 J	11/15	11/15	0.073	2.600	4/7	4/7	0.054	0.160 J

Notes:

- E, J Estimated value (see Appendix A)
-- Not calculated

- 1 Frequency of detection is defined as a/b, where --
a = number of times a compound was detected
b = total number of samples

Sample results which were identified by the laboratory as due to blank contamination are not counted in either a or b.

- 2 Adjusted frequency of detection omits samples from which results were questionable due to other QA/QC problems; only samples included in this column were used to determine geometric mean and maximum concentrations.

TABLE 3-10
ESTIMATED DOSES VIA INGESTION OF CONTAMINATED SOILS
AT BOWERS LANDFILL

Compound ¹	Mean Concentration ² (mg/kg)	Maximum Concentration ² (mg/kg)	Daily Dose ³		Average Lifetime Dose ⁴	
			Probable Case (mg/kg/day)	Worst Case (mg/kg/day)	Probable Case (mg/kg/day)	Worst Case (mg/kg/day)
Inorganic -						
Barium	189	287	4.73 E-04	7.17 E-03	NA	NA
Lead	78	179	1.95 E-04	4.48 E-03	NA	NA
Mercury	0.27	0.43	6.75 E-07	1.08 E-05	NA	NA
Organic -						
Chlordane ⁵	0.015	0.210	3.75 E-08	5.25 E-06	4.40 E-11	6.16 E-09
PCBs	0.238	3.60	NA	NA	6.99 E-10	1.06 E-07
PAHs:						
Benzo(a)anthracene	NA	4.30	NA	NA	--	1.26 E-07
Benzo(a)pyrene	NA	4.30	NA	NA	--	1.26 E-07
Benzo(b)fluoranthene	NA	8.60	NA	NA	--	2.52 E-07
Chrysene	NA	5.20	NA	NA	--	1.53 E-07
Dibenzo(a,h)anthracene	NA	0.960 J	NA	NA	--	2.82 E-08
Indeno(1,2,3-cd)pyrene	NA	2.60	NA	NA	--	7.63 E-08

Notes:

NA Not applicable
-- Not calculated

J Estimated value, organic

1 Only results for indicator chemicals that were detected in at least one on-site or adjacent sampling point are presented. Specifically, benzene, tetrachloroethene, and 4-methylphenol were not detected.

2 Includes samples collected on or adjacent to Bowers Landfill at concentrations above background levels. See Table 3-8 for a list of sampling points.

3 Daily doses were calculated using Equation 3-1, the geometric mean and maximum concentrations observed in the sampling locations on-site or adjacent to Bowers Landfill, and the following assumptions:

Amount Ingested = 0.1 gram (most probable case)
1.0 gram (realistic worst case)
% Absorbed = 50
Body Weight = 20 Kg

4 Average lifetime doses were calculated using Equation 3-2. The geometric means and maximum concentrations observed in the sampling locations on-site or adjacent to Bowers Landfill, and the following assumptions:

Frequency of Contact = 10 days
Years of Exposure = 3 years

5 U.S. EPA has published reference levels for both noncarcinogenic (daily dose) and carcinogenic (average lifetime dose) effects of chlordane; therefore, PRC will evaluate chlordane for both types of effects.

absorption of contaminants adsorbed to soils will be roughly one-half the absorption seen in experimental animals dosed via drinking water or food.] PRC used Equation 3-2 to calculate average lifetime daily doses for carcinogenic indicator chemicals. We assumed that children would ingest soil 10 times per year over a 3-year period.

At least one indicator chemical listed in Table 3-10 could be present in soil from sources other than landfilling activities. Chlordane was found in similar concentrations on the landfill and in agricultural fields west and north of the landfill (see Table 3-9). Chlordane is a pesticide and may have been released to soil through agricultural activities near Bowers Landfill.

PRC did not estimate exposure doses for direct contact with contaminated soils. However, doses via this exposure route should be much lower than ingestion doses since most of the indicator chemicals found in soil are poorly absorbed through the skin.

3.3.6 Inhalation of Contaminated Air

Contaminants may enter the air through two pathways -- volatilization from soils and surface waters and on airborne dust particles that originate from contaminated soils. Though limited air monitoring has revealed no ambient air contamination, the extent of any releases remains unclear. Therefore, PRC did not model the potential inhalation doses.

PRC does not expect air exposures to be significant at Bowers Landfill. Very few volatile contaminants were found in soil or surface water. Contaminants found in these media were mainly metals and organic compounds of low volatility. These contaminants could become airborne if dust is released from the landfill surface. However, the likelihood of significant dust releases is small because the landfill is covered with vegetation and there is very little exposed soil. Furthermore, the road that runs down the center of the landfill is seldom used and is overgrown with vegetation.

The release of dust from agricultural areas adjacent to the landfill during plowing or other farming activities is also of potential concern. However, Table 3-9 shows that soil concentrations for indicator chemicals are generally lower in

agricultural fields than on the landfill. Substantial amounts of dust would have to be generated before air concentrations of indicator chemicals reached hazardous levels.

3.3.7 Ingestion of Contaminated Crops

As discussed earlier, PRC believes that PCBs, barium, and lead have the greatest potential for uptake in crops grown in the field between the landfill and the river. However, no analytical information is available on the contaminant levels that may be in the crops. Due to this lack of information, PRC did not estimate the potential doses from ingesting contaminated crops.

3.3.8 Ingestion of Contaminated Terrestrial Animals and Birds

Under this scenario, the exposed population of interest is the hunters and their families who may ingest terrestrial animals and birds contaminated by releases from the site. Several of the indicator contaminants such as PCBs, PAHs, chlordane, and mercury are known to bioaccumulate. Although Dames & Moore (1987a) conducted a biological survey of the Bowers Landfill vicinity, no tissue samples were taken to determine contaminant levels. PRC did not calculate potential contaminant levels in tissue or human dose levels; however, any exposure via this pathway is expected to be very limited.

3.3.9 Direct Contact with or Ingestion of Contaminated Surface Water and Sediments

Aquatic species in the Scioto River are exposed to contaminants that may originate from the Bowers Landfill site. The contaminant concentrations identified in the Scioto River and sediments are presented in Tables 3-2 and 3-3. These represent the worst case exposure concentrations for aquatic life in the river.

PRC does not consider the landfill to be a significant source of exposure to aquatic life via this pathway for two reasons. First, indicator chemicals were found at relatively low concentrations in river water and sediment. Additionally, concentrations found in samples collected adjacent to and downstream of the landfill were similar to concentrations in upstream samples. This suggests that the landfill contributes little additional contamination to river water and sediment.

3.3.10 Ingestion by Terrestrial Animals and Birds of Contaminated Plant Life

Plant life at or near the landfill and in the Scioto River may uptake contaminants from the site. These plants may be used as a food source by terrestrial animals or birds. No samples have been taken to determine the extent of contamination in the plants and in higher organisms. However, PRC expects the exposure to be limited because of the low contaminant concentrations in soil.

CHAPTER 4

TOXICOLOGIC EVALUATION OF CONTAMINANTS

This chapter summarizes available information on the toxicologic properties of the indicator contaminants at Bowers Landfill. These contaminants are barium, benzene, chlordane, lead, mercury, 4-methylphenol, polychlorinated biphenyls, polynuclear aromatic hydrocarbons, and tetrachloroethene. The purpose of this chapter is not to present a comprehensive literature review, but rather to summarize the toxicology of each indicator contaminant in light of the exposure routes identified at Bowers Landfill (air, soil, ground water, and surface water). In compiling and analyzing this information, PRC relied on authoritative reviews rather than the original literature.

The summaries present information on the pharmacokinetics (absorption, metabolism, and excretion), acute and chronic toxicity, teratogenicity, carcinogenicity, and the toxicity of each contaminant for aquatic and terrestrial species. Applicable standards, guidelines, and criteria for the contaminants are identified. This information is then used in later chapters in performing the exposure assessment and risk characterization for the site. A glossary of toxicologic terms used in this chapter is presented as Appendix C.

4.1 BARIUM

Barium is widely distributed in the environment, with small amounts accompanying calcium in practically all biologic and geologic systems. Barium, one of the alkaline earth metals, has been reviewed in Stokinger (1981), U.S. EPA (1984b), Carson and others (1986), Goyer (1986), and the National Library of Medicine (1987).

Absorption of barium compounds depends on the solubility of the compound, and averages 2 percent for normal dietary barium. Barium is distributed throughout the body, with about two-thirds being deposited in the bones. Excretion is slow and occurs primarily through the feces. Some barium is excreted in the urine, but almost all of this is then absorbed in the renal tubes.

The acute toxicity of barium is seen mostly in its effects on muscle tissue; stimulation is followed by paralysis, probably by barium's interfering with potassium transport to produce a characteristic hypokalemia (insufficient potassium in the blood). Initial symptoms are gastrointestinal (nausea, vomiting, colic, diarrhea). Later symptoms include tingling in the extremities and electrocardiographic irregularities leading to cardiac fibrillation, general muscle paralysis, and death from respiratory arrest.

The chronic toxic effects of barium are not well-defined, except for baritosis, an occupational pneumoconiosis produced by inhalation of barite (an insoluble sulfate salt, the most commonly occurring barium mineral). One epidemiologic study found increased blood pressure and cardiovascular deaths in people with high natural levels of barium in their drinking water. The few animal studies have found only nonspecific effects (reduced longevity). There is no evidence of carcinogenicity or teratogenicity.

Limited information is available on the toxicity of barium to aquatic life. The only study located by PRC stated that the 28-day, 96-hour LC50 for rainbow trout was 42.7 mg/L (Birge and others, 1980), indicating barium's low toxicity compared to other metals.

4.2 BENZENE

Benzene is the simplest cyclic aromatic hydrocarbon. Due to its wide use as a solvent and its interesting toxicologic properties, benzene has been repeatedly studied and reviewed (Sandmeyer, 1981; U.S. EPA, 1984c; Andrews and Snyder, 1986; National Library of Medicine, 1987). The most common route of toxic exposure is inhalation. Therefore, almost all data are from inhalation studies; the only significant exceptions are data from massive single oral doses.

Benzene is apparently well-absorbed by the lungs and the gastrointestinal tract, although pure liquid benzene is irritating. Much of a large dose is exhaled unchanged. The rest, and all of lesser doses, is metabolized through the epoxide to phenol (with minor quantities further hydroxylated), conjugated to sulfate or glucuronide, and excreted in the urine. Chronic toxic effects are due to one or more of the metabolites, rather than to benzene itself.

Signs of acute toxicity are dominated by central nervous system depression: staggering walk, stimulation followed by drowsiness, and coma followed by respiratory failure and circulatory collapse.

Chronic exposure most significantly affects the hematopoietic system. These effects have been seen only in industrial workers exposed to high concentrations. The usual initial signs are blood-clotting defects, caused by platelet alterations, and a generally reduced production and concentration of all types of blood cells. As the syndrome progresses, the bone marrow becomes hyperplastic, then hypoplastic, and internal hemorrhaging occurs. Finally, a progressive bone marrow aplasia occurs. Some patients develop leukemia. This human effect has been hard to replicate in animals, but benzene is considered a proven human carcinogen.

Benzene has been reported to cause chromosomal alterations in humans, but the data are confounded because these people were exposed to many other chemicals. Benzene has been found mutagenic in a number of test systems. In various reproductive studies, benzene was not considered fetotoxic because effects were seen only when doses also caused maternal toxicity.

Benzene has been found toxic to all animal species studied. Most aquatic toxicity studies found adverse effects only at concentrations over 5 mg/L (Hermens and others, 1985). In the few cases studied, the minimal toxic dose in chronic studies was little different from that in acute studies.

4.3 CHLORDANE

Chlordane is an insecticide of the chlorinated cyclodrene class, which also includes aldrin, dieldrin, endrin, and heptachlor. All these chemicals are qualitatively very similar, with chlordane being the least toxic. Chlordane toxicity has been reviewed by Deichmann (1981), U.S. EPA (1984e), Murphy (1986), and National Library of Medicine (1987).

Chlordane is absorbed from the gastrointestinal tract and lungs and, to some extent, through the skin. It is deposited in the body fat, which acts as a reservoir

for chlordane and prolongs its effects. Chlordane is oxidized in the liver; most excretion is through the bile into the feces, but some is excreted into the urine.

Acute toxicity is rarely seen, but primarily affects the central nervous system. Effects include loss of appetite, irritability, hyper-excitability, vomiting, and tremors, leading to convulsions and death. In some cases, hepatotoxicity is seen. With chronic toxicity, the main effect is on the liver, often seen as depressed weight gain in low-dose animal studies. Chronic toxicity also affects the central nervous system; effects include electroencephalogram changes and irritation at the exposure site (lung edema or gastrointestinal tract irritation). Chlordane is carcinogenic to mouse livers and is considered an animal carcinogen and a probable human carcinogen. No specific teratology has been seen, but chlordane is transported across the placenta and excreted into milk, thereby producing toxicity in offspring.

Chlordane is rather toxic to aquatic species, with acute LC50s as low as 11.5 ug/L (for brown trout, Salmo trutta) and 10 ug/L (midge larvae, Chironomus plumosus). Few chronic studies were found, but the highest acceptable level for the dunegrass crab (Cancer magister) was only 0.015 ug/L. The ecotoxicity of chlordane is increased by its bioconcentration. Various tests have found bioconcentration values ranging from about 100 to about 6,000 after only 96 hours of exposure. This bioconcentration reflects the concentration in fat seen in mammals.

4.4 LEAD

Lead toxicity has been intermittently studied since the time of Hippocrates. This overview is based on authoritative reviews including Stokinger (1981), U.S. EPA (1984d), Carson and others (1986), and Goyer (1986).

Normal adults absorb about 10 percent of an oral dose of lead compound; however, the specific amount absorbed depends on the nature of the compound and on the individual. Absorption increases in children (up to 50 percent) and under some dietary conditions. About half the lead is deposited in the mineral matrix of the skeleton; the rest is widely distributed. Lead is not metabolized, but its interactions with enzymes, especially sulfur-containing enzymes, produce its toxic effects. Excretion, mostly in the urine, is very slow; the half-life of lead in bone

is about 20 years. Large single doses of lead produce fatigue, sleep disturbances, and constipation, followed by colic, anemia, and neuritis. Chronic lead poisoning produces loss of appetite, metallic taste, constipation and obstipation, anemia, pallor, malaise, weakness, insomnia, headache, nervous irritability, muscle and joint pains, fine tremors, encephalopathy, and colic. Other effects may include certain muscular weaknesses ("wrist drop") and lead encephalopathy, which may include learning defects in children.

Lead is not carcinogenic, but it has severe reproductive toxicity. It can produce premature deliveries and spontaneous abortions in women and sterility in men.

The major population at risk is young children, the group most sensitive to lead's effects, in urbanized low-income areas. Children in these areas are exposed to lead in automobile exhaust, old paint, and so on. The second most significant population at risk is pregnant women in those same areas.

Acute and chronic toxic effects of lead have been studied in a number of different aquatic organisms. Increased water hardness has a protective effect on fish exposed to lead; however, the actual protective mechanism is not completely understood. U.S. EPA (1980c and 1983b) in its review of acute toxicity tests noted that lead was more toxic to Daphnia magna, rainbow trout, fathead minnow, and bluegill in soft water than in hard water. U.S. EPA (1983b) noted that at a water hardness of 50 mg/L, acute toxicities ranged from 148.9 ug/L for scuds to 236,600 ug/L for midges.

Results from chronic tests using freshwater aquatic organisms show the same relationship between lead toxicity and water hardness as seen in acute tests. Lead has been shown to be 11 times more toxic to Daphnia magna in soft water than in hard water. Lead has caused spinal deformities in rainbow trout, brook trout, northern pike, and walleye (U.S. EPA, 1980c). The lowest chronic toxicity value reported was for a cladoceran at 12.37 ug/L in soft water.

4.5 MERCURY

The toxicity of mercury has been studied for many centuries. This overview is based on authoritative reviews including Stokinger (1981), U.S. EPA (1984g), Carson and others (1986), Goyer (1986), and Eisler (1987).

Mercury toxicity is complicated because mercury comes in three chemical forms: the metal, a liquid with significant volatility; inorganic compounds, including divalent (mercuric) and the less stable monovalent (mercurous) ones; and organic compounds, including methylmercury, the most toxic mercury compound in most systems. In environmental systems each of the three forms react to form one or both of the other forms, but reaction rates vary widely, depending on the precise environmental conditions.

Mercury metal is well absorbed through the respiratory tract, but there is negligible absorption from the gastrointestinal tract and through the skin. Inorganic mercury is absorbed poorly from the gastrointestinal tract (about 7% in humans) and through the skin, and very poorly from the respiratory tract. Organic mercury is well absorbed by all routes, and therefore more potent as a toxicant. Once absorbed, the kidneys have the greatest concentrations of metallic and inorganic mercury, while the brain and red blood cells have more organic mercury. Metallic mercury is exhaled to some extent. All forms are excreted in the feces and, later, in the urine; small amounts are deposited in the hair. All forms are biologically converted to the mercuric form, which then reacts with sulfur-containing molecules to produce mercury's toxic effects. In some species, selenium protects against this toxicity.

Acute mercury toxicity is rarely seen; the effects are primarily irritation at the sites of contact. Death results from ulceration leading to bleeding and shock, from kidney toxicity, or from both.

Chronic poisoning develops very slowly. "Mercurialism", from metallic and inorganic mercury, first affects the central nervous system, with symptoms like excitability, irascibility, depression, fatigue, drowsiness, and insomnia. Next, the victim develops muscular tremors, first in the hands, followed by paresthesias and nephrotoxicity. Other effects sometimes seen include chronic inflammation (inside

the nose, the gums, the stomach). Organic mercury causes "Minimata Disease", which mimics encephalitis. The first signs are decreases in the senses of touch, vision, hearing, and taste, leading to numbness, tremors, and incoordination. Mood changes often occur, as with mercurialism.

Mercury is not teratogenic, but it readily crosses the placenta. The young are more sensitive, even before birth, especially to organic mercury. Therefore, there is a high incidence of pre- and post-natal mortality, usually from nervous system malfunctions, resulting in greatly decreased reproduction. There is no evidence of carcinogenicity.

Most tests of mercury toxicity to aquatic organisms have involved acute studies. Mercury is more toxic to young organisms and more toxic in flow-through tests than in static tests. For Daphnia magna, the 96-hour LC50 is 5.0 ug/L, while the lifetime LC50 is 1.3 to 1.8 ug/L. With rainbow trout, the 96-hour LC50 for juveniles is 155 to 200 ug/L, while 28-day LC50s for embryo-larval stages are 4.7 ug/L in a static test and less than 0.1 ug/L in a flow-through test. Similar results are seen with channel catfish and large-mouth bass. For a series of amphibians, the 96-hour LC50 for tadpoles ranged from 1.3 ug/L (narrow-mouthed toad), through 7.3 ug/L (leopard frog), to 107.5 ug/L (marbled salamander).

Few studies have been done with non-aquatic species, except for collecting wild specimens and analyzing tissues for mercury. However, it is known that mercury biomagnifies; that is, fish-eating birds have higher body burdens than their prey, and carnivores (such as raccoon and fox) have higher levels than herbivores (such as muskrat and beaver) living in the same area.

4.6 4-METHYLPHENOL

4-Methylphenol, or para-cresol, is usually seen commercially as cresylic acid, a mixture of all three methylphenol isomers. Limited information is available on the 4-methylphenol isomer through reviews by Deichmann and Keplinger (1981), U.S. EPA (1984f), and National Library of Medicine (1987). This information has been supplemented with information on the methylphenol mixture and occasionally with information on the parent compound, phenol. All phenol and methylphenol isomers are quite similar, although 3-methylphenol is generally considered the least toxic.

4-Methylphenol is well-absorbed through the skin and from the lungs and gastrointestinal tract. It is metabolized in the liver by oxidation and conjugation. Most excretion occurs in the urine, but some excretion occurs through the bile into the feces.

The initial toxic effect of 4-methylphenol is local irritation; this is severe enough to classify the compound as corrosive. Large acute doses, regardless of exposure routes, lead to muscular weakness, gastrointestinal disturbances, severe central nervous system depression, collapse, and death. These effects may be accompanied by various lesions in the liver, kidneys, pancreas, and spleen, especially after repeated doses. Some studies show increased leukocyte levels, but this may be a reaction to tissue damage.

No chronic studies have been reported, but skin-painting studies have shown that 4-methylphenol promotes the carcinogenicity of polynuclear aromatic hydrocarbons when repeated doses of 4-methylphenol were given after the carcinogen application. This effect may be seen in tobacco smoke, which contains various phenol derivatives, as well as many polynuclear aromatic hydrocarbons.

No data on reproductive toxicity have been found.

Limited data are available on the aquatic toxicity of 4-methylphenol. Hodson and others (1984) reported a 96-hour LC50 for rainbow trout of 7.87 mg/L using 4-methylphenol. Additional data was found on cresol compounds. Gerisich and Mayes (1986) reported a 48-hour LC50 of 2.0 mg/L for Daphnia magna, and Slooff (1983) tested 15 macroinvertebrates with a 48-hour LC50 ranging from 10 to 165 ug/L. PRC did not find any data on the chronic toxicity to aquatic organisms.

4.7 POLYCHLORINATED BIPHENYLS

The following review of the human toxicity of polychlorinated biphenyls (PCB) makes use of recent authoritative reviews, including Deichmann (1981), NIOSH (1986), and the National Library of Medicine (1987). Virtually all data are for PCB mixtures; the most studied are Aroclor 1254 and Aroclor 1260, but differences are minor.

PCB is absorbed through all routes: by ingestion, inhalation, and transdermal absorption (through the skin). Most occupational exposure is transdermal, while most environmental incidents have involved ingestion. After being absorbed, PCB is widely distributed and concentrated in fatty tissues, which tend to become reservoirs. Metabolism occurs in the liver, usually through hydroxylation of the aromatic rings. Excretion occurs in the urine and through the bile in the feces, with the ratio of the two routes varying considerably among species. Excretion is quite slow, due to the slow emptying of the reservoirs.

-PCB exposure increases the activity of many hepatic drug-metabolizing enzymes in the many animal species studied. Therefore, many interactions occur between PCB and other toxicants. The combined toxicity of PCB and other toxicants may be greater or less than that predicted by simple addition; however, in the absence of specific experiments, it is not possible to predict the toxicity of the combination.

No data are available on the acute toxic effects of PCB in humans. All reported cases involved persons being exposed at least 5 days per week who developed effects weeks or months after subchronic or chronic dosing. In animals given very large acute doses, acute toxicity is seen as a variety of lesions in the liver, leading to wasting away and death in days or weeks. The slow onset of symptoms in humans probably reflects both the slow development of toxic effects, as seen in the animal studies, and an accumulation of PCB in reservoirs, with subsequent leaching, as noted above.

Chronic PCB poisoning produces a wide variety of effects in humans. These effects are basically the same regardless of the route of exposure. Symptoms include many skin lesions; chloracne is the most characteristic, but other symptoms include hyperpigmentation of the skin, eye area effects (edema of the eyelids; hyperactivity of the secretory glands in the upper eyelids; inflammation of the eyelid lining), lesions in the hair follicles, and general subcutaneous edema. More severe lesions tend to appear at the point of contact -- either the skin (as in the hands of a worker) or the stomach lining (as seen in some feeding experiments). Lesions in the stomach lining cause nausea, diarrhea, and other gastrointestinal effects. PCB also affects the liver (degenerative lesions, manifesting themselves as jaundice and effects on serum enzyme levels) and the blood-forming organs (an

increase in white cells, which may be a reaction to the skin lesions, and a decrease in red cells). There is some evidence of peripheral neuropathy, characterized by numbness of the extremities. In occupational studies, the minimum effects are chloracne and serum enzyme disturbances. Studies of the relative toxicity of various PCBs in animal species have not been consistent. In some studies, the more chlorinated mixtures, such as Aroclor 1254 and Aroclor 1260, were more toxic; in other studies, there were no noticeable differences.

PCB has been demonstrated to be carcinogenic to the livers of animals. PCB is probably carcinogenic in humans when given in a sufficient dosage for sufficient periods of time. However, human tumors have not been identified as PCB-induced.

PCB has adverse effects on reproduction. In the Yusho, Japan, epidemic (caused by rice bran oil contaminated with 1,500 to 2,000 mg/kg of PCB plus polychlorinated dibenzofurans, which have similar toxic effects), two infants were stillborn, and others born to affected mothers had decreased birth weight and skin discolorations. Animal studies have reported high concentrations of PCB in milk, probably due to the PCB being dissolved in the fat. The adverse effects of PCB on reproduction have been confirmed in many animal species; the usual effects are non-specific, such as decreased survival and body weight.

Studies conducted on rodents and monkeys have found that PCB suppresses the immune response. These effects are the result of high doses and have not been confirmed in humans.

U.S. EPA (1980a) reviewed the available aquatic toxicity data in establishing the ambient water quality criteria for PCBs. As described earlier, PCBs have low water solubility, and this has governed the exposure levels in toxicity tests. Also, PCBs are mixtures of several isomers with ranging degrees of chlorination; these mixtures are known by the trade name Aroclor. Most toxicity testing of PCBs involved various Aroclors.

The acute toxicity testing of PCBs has involved invertebrates and vertebrates. The acute values for freshwater invertebrates ranged from 10 ug/L to 400 ug/L; the values for newly hatched freshwater fish ranged from 2.0 ug/L to 7.7 ug/L (U.S. EPA, 1980a).

The chronic toxicity of PCB was determined by a number of studies (U.S. EPA, 1980a). The chronic values for freshwater invertebrates ranged from 0.8 ug/L to 4.9 ug/L; for fish the range was 0.3 ug/L to 9.0 ug/L. Most of the variations reported were due to the various Aroclors tested rather than species tested.

4.8 POLYNUCLEAR AROMATIC HYDROCARBONS

Polynuclear (or polycyclic) aromatic hydrocarbons (PAH) are chemicals containing three or more fused, aromatic hydrocarbon rings. They are generally found as a highly complex mixture in the products of incomplete combustion (coal soot, cigarette smoke, motor vehicle exhaust, and so on). Seventeen PAHs are included on U.S. EPA's Hazardous Substances List, but few are well-studied. This section focuses on the best-studied PAH, benzo(a)pyrene (BAP). Most data would apply, however, to all PAHs. Reviews include Sandmeyer (1981), U.S. EPA (1984a), Williams and Weisburger (1986), and National Library of Medicine (1987).

Absorption of BAP and other PAHs has been demonstrated indirectly, since toxic effects have been seen after oral and inhalation exposure. PAHs are oxidized in the liver by an enzyme, aryl hydrocarbon hydroxylase (AHH), to the epoxide, which hydrolyses to the dihydroxy derivative. The metabolites are the active forms of the chemicals; variations in the formation (amount, rate, products) of these metabolites account for the different effects of the various PAHs. PAHs also cause the synthesis of greater quantities of AHH and other drug metabolizing enzymes; therefore, simultaneous exposure to PAHs and other toxicants increase or decrease the toxicity of the other toxicants. A few non-metabolic interactions also exist. For example, BAP increases the cardiac sensitization effects of trichloroethene. PAHs are excreted as a large variety of oxidized metabolites and conjugates mostly through the bile into the feces.

Single, acute oral and dermal doses of PAHs are practically nontoxic. Repeated doses of straight-chain PAHs (anthracene, naphthalene, pentacene, and so on) also have little effect. PAHs in large doses produce weight loss and possibly blood effects (even aplastic anemia) and some liver and kidney lesions, but do not seem to be carcinogenic. Other PAHs are carcinogenic after repeated doses by oral, inhalation, and dermal routes. Tumors develop at the entry site (stomach, lung,

skin) and in the liver, breast, and occasionally at other sites. Other effects are like straight-chain PAHs. Dibenzo(a,h)anthracene was the first pure chemical shown to be carcinogenic to animals in experiments during the 1920s, while coal soot, now known to be primarily PAHs, was recognized as the cause of scrotal cancers in chimney sweeps in 1775. Several of the PAHs, including BAP, are routinely used in the laboratory to induce tumors in rodents; a few laboratory workers have developed similar tumors from accidental exposures to these chemicals. PAHs are also believed to be the principal carcinogenic component of tobacco smoke.

PAHs have little, if any, reproductive toxicity in the few available studies. The limited studies are available on the toxicity of benzo(a)pyrene to aquatic organisms. U.S. EPA (1982a) reported a study that found 87 percent mortality in blue gill after 6 months of exposure at 1.0 mg/L with a related compound, benzo(a)anthracene. The study also reported increased tumors in benthic fish associated with sediments containing high PAH levels.

4.9 TETRACHLOROETHENE

Tetrachloroethene is a commonly used industrial solvent. It has been reviewed by U.S. EPA (1980b, 1983a, 1986b), Torkelson and Rowe (1981), and National Library of Medicine (1987).

Tetrachloroethene is well-absorbed from the lung, but less so from the gastrointestinal tract and through the skin. It is widely distributed throughout the body, with deposits in fat. Most tetrachloroethene is exhaled unchanged, but some is metabolized in the liver and excreted in the urine. The amount of this metabolism varies greatly among species; the metabolites, especially the highly reactive epoxide, are believed responsible for the compound's carcinogenicity and some other toxic effects.

The major acute toxic effect of tetrachloroethene is central nervous system depression. Other effects include irritation (especially of mucous membranes) and lesions in the liver and kidneys. Tetrachloroethene is less potent than other chlorinated hydrocarbons in terms these effects; for instance, it cannot produce surgical anesthesia.

Repeated doses produce considerable hepatotoxicity and, often, nephrotoxicity. Rarer effects include pulmonary edema (after inhalation) and dermatitis due to skin defatting (after dermal contact). There is no evidence of teratogenicity in the few available studies. Tetrachloroethene is carcinogenic in animal studies, and therefore considered a probable human carcinogen. However, limited human studies have found no carcinogenicity. This finding has been attributed to the proportionately lower metabolism in humans as compared to rodents.

Little attention has been paid to the environmental toxicity of tetrachloroethene, primarily because of its low persistence in water resulting from its high volatility. In reported toxicity studies, the rainbow trout (Salmo gairdneri) is the most sensitive species with a 48-hour LC50 of 4,200 ug/L. Other animal species, Daphnia magna and various fish, had LC50s ranging from 12,900 to 21,400 ug/L. The green alga Selenastrum capricornutum was not affected at much higher concentrations (up to 816,000 ug/L), although a study in an experimental pond found the elimination of four of six phytoplankton species after an initial concentration of only 440 ug/L. The only chronic study used the fathead minnow, Pimephales promelas, and found that the effects at 840 ug/L of chronic dosing were similar to those at 13,460 ug/L of acute dosing.

4.10 EXPOSURE STANDARDS, CRITERIA, AND GUIDELINES

Environmental standards, criteria, and guidelines can be used to evaluate the potential effects of exposure to the contaminants of concern at the Bowers Landfill site. Government agencies have established these contaminant levels to define acceptable or quantifiable levels of risk for exposure to contaminants in various media. Standards, guidelines, and criteria for various media are shown in Table 4-1. The rationale for some of these criteria is further discussed below.

Under the Safe Drinking Water Act, U.S. EPA establishes two types of standards for public water systems: maximum contaminant level goals (MCLG) and maximum contaminant levels (MCL). MCLGs are non-enforceable health goals set at levels that result in no known adverse health effects, considering an adequate margin of safety. MCLs are enforceable drinking water standards set as close to MCLGs as feasible, after accounting for analytical, technical, and economic considerations. MCLs and MCLGs are listed in 40 CFR Parts 141 and 143.

TABLE 4-1
REGULATORY STANDARDS AND GUIDELINES FOR INDICATOR CHEMICALS

Parameter	Barium	Benzene	Polynuclear Aromatic Hydrocarbons	Chlordane	Lead	Mercury	4-Methyl- phenol	Poly- chlorinated Biphenyls	Tetrachloro- ethene
Maximum Contaminant Level (ug/L) ^a	1,000	5	--	--	50	2	--	--	--
Proposed MCL (ug/L) ^b	NA	NA	--	--	NA	--	--	--	--
MCL Goal (ug/L) ^c	NA	0	--	NA	NA	--	--	--	--
Proposed MCLG (ug/L) ^d	1,500	NA	--	0	20	3	--	0	--
Acute Health Advisory (ug/L) ^d (1-day)	510 ^j	223	--	60 ^j	--	1.58 ^j	--	--	2,000 ^j
Lifetime Health Advisory (ug/L) ^d	1,500 ^j	--	--	--	20 ^j	1.1 ^j	--	--	10 ^j
Water Quality Criteria (Ingestion of Drinking Water) (ug/L) ^d	--	0.67	0.0031	0.022	50	10	--	0.0126	0.88
WQC (Ingestion of Aquatic Organisms) (ug/L) ^d	--	40	0.031	0.48	-- (ng/L)	0.146	--	0.079	8.85 (ng/L)
Aquatic WQC, Acute (ug/L) ^e	--	5,300 ^l	--	2.4	34	2.4	--	2.0	5,280 ^l
Aquatic WQC, Chronic (ug/L) ^e	--	--	--	0.0043	1.3	0.012	--	0.014	840 ^l
TLV (mg/m ³) ^f	0.5	30	--	0.5	0.15	0.05	22	0.5 to 1.0	335
Acceptable Intake, Chronic Exposure (mg/kg/day) ^d	5.7E-02 ^m	--	--	5.0E-05	1.4E-03	3.0E-04 ^k	5.0E-02	--	2.0E-02
Oral Carcinogenic Potency Factor (mg/kg/day) ^g	NA	0.052	11.5	1.30 ^m	NA	NA	--	7.00 ^m	0.051
Evidence of Carcinogenicity ^d (Oral route)	NA	A	--	B2	NA	NA	--	B2	B2

TABLE 4-1 (Continued)
REGULATORY STANDARDS AND GUIDELINES FOR INDICATOR CHEMICALS

Notes:

- a 40 CFR 141.11
 - b U.S. EPA November 13, 1985c, Federal Register
 - c 40 CFR 141.50
 - d Superfund Public Health Evaluation Manual (U.S. EPA, 1986a), unless otherwise noted; WQC for carcinogens based on a risk of one cancer per 1 million population
 - e U.S. EPA November 28, 1980d Federal Register, July 19, 1985d Federal Register (assumes hardness of 50 mg/L CaCO_3)
 - f ACGIH (1987)
 - g Carcinogen Assessment Group, Carcinogenicity Data Base (1986)
 - h A = Human carcinogen; B = probable human carcinogen (B1 = limited human evidence; B2 = sufficient animal evidence but inadequate human evidence);
C = possible human carcinogen. From CAS (1986)
 - i 20 ug/day from all sources
 - j U.S. EPA (1987)
 - k Value listed is for organic (alkyl) mercury
 - l Value represents a threshold level for toxic effects, but is not formally considered a WQC
 - m Lee (1987)
 - NA Not applicable
 - Not available
-

The U.S. EPA Office of Drinking Water has developed health advisories (HA). The levels in these advisories are based on non-carcinogenic health effects. Synergistic effects of other chemicals are not considered, but the HA factors in a margin of safety. HAs are calculated for a 10 kg child consuming 1 liter of water per day. Although 1-day, 10-day, and chronic HAs are available, the latter two values are most appropriate to long-term exposures.

U.S. EPA has also established ambient water quality criteria (AWQC) as directed by Section 304 of the Clean Water Act. The criteria have no regulatory impact, but are intended to serve as guidelines for protecting human health and the environment from effects of pollutants. To protect human health, AWQC establish maximum concentrations for exposure directly through ingestion of water and indirectly through consumption of aquatic organisms found in ambient water. The aquatic criteria presented in Table 4-1 assume that freshwater aquatic organisms should not be adversely affected by a contaminant if the 4-day average concentration and the 1-hour average concentration are not exceeded more than once every 3 years.

Threshold limit values (TLV) are set by the American Conference of Governmental Industrial Hygienists as levels in air expected to have negligible adverse effects in almost all healthy workers exposed 8-hours per day, 40-hours per week. These would be excessive exposures for the general population on a continuous basis. For metals, these levels often vary depending on the physical and chemical form of the metal. The National Air Ambient Quality Standards (NAAQS) are designed by the U.S. EPA to protect the general population. U.S. EPA has published NAAQS for only a small number of air pollutants. Of the chemicals of concern at Bowers Landfill, only lead has a NAAQS (1.5 ug/m^3 , 40 CFR 50.12). This value is lower by a factor of 100 than the TLV for lead in Table 4-1.

The acceptable intake for chronic exposure (AIC) is the highest human intake of a chemical that should not cause adverse health effects when exposure to this chemical is long-term (lifetime). AICs are expressed in units of mg/kg/day. They consider only noncarcinogenic health effects and are usually based on the results of chronic animal studies.

The carcinogenic potency is calculated by the U.S. EPA's Carcinogen Advisory Group on the basis of animal studies at relatively large doses. The dose-effect data from these studies are mathematically manipulated to calculate a slope factor. From the many available factors, the largest is chosen as the chemical's "carcinogenic potency." This parameter, multiplied by the exposed person's intake (in the proper dosage units), estimates the probability of developing a cancer after a lifetime exposure.

CHAPTER 5

RISK CHARACTERIZATION

The purpose of this chapter is to assess the risk associated with contaminant releases from Bowers Landfill. PRC applied the information reported in previous chapters to determine the actual or potential health and environmental risks resulting from exposure via each of the 10 scenarios presented in Chapter 3.

5.1 INGESTION OF CONTAMINATED GROUND WATER

Contamination has been identified in the downgradient monitoring wells at Bowers Landfill in both the upper and lower aquifers. At present, no drinking water wells are known to exist in the upper aquifer between the landfill and the river (the direction of ground-water flow). Furthermore, no wells are known to exist in the lower aquifer within 1 mile downgradient of the site. Therefore, the risk characterization focuses on the potential risk to future receptors who may use the ground water at the site as a drinking water source.

To evaluate this potential risk, PRC used both qualitative and quantitative methods. Table 3-4 presented the mean and maximum downgradient concentrations found in the ground water at the site and the corresponding most probable and realistic worst case daily dose and average lifetime dose for persons who might drink this water.

To evaluate the potential noncarcinogenic risks from ingesting ground water, PRC used a hazard index (HI) approach based on U.S. EPA's guidelines for evaluating risks caused by exposure to mixtures of chemicals (U.S. EPA, 1986a). This approach assumes (1) that multiple subthreshold exposures could result in an adverse effect and (2) that the magnitude of the effect will be proportional to the sum of the ratios of the subthreshold exposures to acceptable exposures. This is expressed in the equation below.

$$\text{Hazard Index (HI)} = \frac{E_1}{RL_1} + \frac{E_2}{RL_2} + \dots + \frac{E_i}{RL_i} \quad (5-1)$$

E_i = Exposure level for the i th toxicant
 RL_i = Reference level for the i th toxicant

PRC compared the estimated doses for the noncarcinogenic contaminant (barium) detected in wells downgradient of Bowers Landfill, at concentrations greater than the upgradient wells, with acceptable daily intake levels for chronic exposure (AIC) to this contaminant. U.S. EPA (1986a) AICs are derived from results of animal studies or observations made in human epidemiologic studies on the relationship between chemical intakes and toxic effects. AICs are based on long-term exposure studies and are designed to protect sensitive populations. The daily doses (from Table 3-4), AIC (from Table 4-1), and HI for barium are presented below.

<u>Chemical</u>	<u>AIC</u> <u>(mg/kg/day)</u>	<u>Probable Case</u> <u>Daily Dose</u> <u>(mg/kg/day)</u>	<u>HI</u>	<u>Realistic</u> <u>Worst</u> <u>Case Dose</u> <u>(mg/kg/day)</u>	<u>HI</u>
Barium	5.70 E-02	9.43 E-03	0.17	5.91 E-02	1.04

An HI greater than one indicates a potential risk (U.S. EPA, 1986a). As indicated above, there is a potential noncarcinogenic risk (HI = 1.04) associated with ingesting contaminated ground water that contains barium at the maximum concentration (realistic worst case) found downgradient of the site.

PRC also estimated the potential carcinogenic risk from lifetime ingestion of ground water immediately downgradient of Bowers Landfill. This estimate focuses on the one carcinogenic indicator chemical identified in the ground water -- benzene. Risk estimates were obtained using the following equation:

$$\text{Incremental Carcinogenic Risk} = \text{Carcinogenic Potency Factor (mg/kg/day)}^{-1} \times \text{Average Lifetime Dose (mg/kg/day)} \quad (5-2)$$

Carcinogenic potency factor (from Table 4-1), average lifetime doses (from Table 3-4), and incremental carcinogenic risks are presented below.

	Carcinogenic Potency Factor	Probable Case Average Lifetime Dose	Incremental Cancer Risk	Realistic Worst Case Average Lifetime Dose	Incremental Cancer Risk
<u>Chemical</u>	<u>(mg/kg/day)⁻¹</u>	<u>(mg/kg/day)</u>	<u></u>	<u>(mg/kg/day)</u>	<u></u>
Benzene	5.2 E-02	2.00 E-05	1 E-06	1.71 E-04	9 E-06

The estimated upperbound incremental carcinogenic risk is approximately 1 cancer per million people under the probable case and 9 cancers per million people under the realistic worst case. The mean concentration used in the probable case estimate (0.7 ug/L) is well below the Safe Drinking Water Act maximum contaminant level (MCL) of 5 ug/L. The realistic worst case estimate is based on a concentration just above the MCL (6 ug/L) and assumes that people will consume ground water containing the maximum concentration of benzene for a 70-year lifetime; this risk may be an overestimate.

Based on the noncarcinogenic and carcinogenic evaluations, there appears to be a potential risk associated with the ingestion of ground water downgradient of Bowers Landfill. It must be noted, however, that since a limited number of samples had detectable and quantifiable contaminant concentrations, the risk identified in the above analysis may be an overestimate. The actual risk may be lower. Further, there is a low probability that the ground water between Bowers Landfill and the Scioto River would be used as a drinking water source because this area is frequently flooded.

5.2 DIRECT CONTACT WITH OR INGESTION OF CONTAMINATED SURFACE WATER

To evaluate the potential risk via direct contact with or ingestion of contaminated surface water, PRC focused on the exposure with the greatest potential risk -- ingestion of surface water. Surface water at the site is not presently used as a drinking water source and is not expected to be used as such in the future; therefore, PRC assumed that any intake will be incidental. As stated in

Chapter 3, PRC did not calculate an incidental ingestion dose due to the very limited exposure anticipated. To evaluate the potential risk from this exposure scenario, PRC chose to compare the maximum surface water concentrations (Table 3-6) to available guidelines or criteria that reflect acute or short-term exposure. When these were unavailable, PRC compared the maximum concentration to guidelines or criteria that were based on chronic (long-term) or lifetime exposure. In most cases, PRC compared the maximum concentrations to Health Advisories developed by U.S. EPA under the Safe Drinking Water Act (Table 4-1). These criteria often have values for 1-day, 10-day, or longer-term exposures.

The maximum contaminant concentrations identified in samples from drainage ditches and the Scioto River (adjacent to or downstream from Bowers Landfill) are compared to available guidelines or criteria below:

<u>Chemical</u>	<u>Scioto River (ug/L)</u>	<u>Drainage Ditches (ug/L)</u>	<u>Guideline or Criterion (ug/L)</u>	<u>Exposure Period</u>
Barium	59**	199*	510 (HA)	1 day
Lead	ND	8.6	20 (HA)	Long term
Mercury	0.2	0.27	1.58 (HA)	1 day
PCBs	ND	2.6	0.0126 (AWQC)	Long term
Tetrachloroethene	1.1**	ND	2,000 (HA)	1 day

HA	Health Advisories
AWQC	Ambient water quality criteria -- lifetime exposure
ND	Chemical was not detected or results were rejected due to quality control limitations
*	Concentration is estimated since compound was detected below the CRDL
**	Concentration found in river adjacent to or downstream from Bowers Landfill was less than or equal to concentration in upstream samples

Maximum concentrations for four of the five indicator chemicals are well below guidelines; average concentrations would be even lower. The only contaminant that exceeds a criterion is PCBs; maximum (and average) concentrations exceed the ambient water quality criterion (AWQC). The AWQC, however, assumes lifetime ingestion of 2 liters of water per day; therefore, the criterion is not directly applicable to the limited exposure that would occur under this scenario.

PRC expects the risk from incidental ingestion of surface water near Bowers Landfill to be very low due to the infrequent exposure and the low contaminant levels found at the site. The risk via direct contact would be even less because the dose entering the body would be much lower than for incidental ingestion.

5.3 DIRECT CONTACT WITH CONTAMINATED SEDIMENTS

Seven of the indicator chemicals were found in sediments collected from drainage ditches near Bowers Landfill and from the Scioto River. Concentrations of these indicator chemicals were listed in Table 3-7. Exposure via direct contact with contaminated sediments is expected to be limited to individuals who wade through or fall into the ditches or river. Exposure doses should be low because none of the indicator chemicals in sediments easily transfers from sediment particles to the skin. Therefore, the risk from direct contact with sediments is probably very low.

5.4 INGESTION OF CONTAMINATED AQUATIC ANIMALS

Humans can be exposed to contaminants through ingestion of aquatic life taken from the Scioto River. However, the surface water contaminant concentrations presented in Table 3-6 suggest a limited impact on the Scioto River from site releases. Of the 9 indicator chemicals, only mercury was found above background (upstream) levels in samples collected adjacent to or downstream from Bowers Landfill.

To evaluate the potential risk for this exposure scenario, PRC compared the geometric mean and maximum mercury concentrations in the river water to the AWQC for ingestion of aquatic life (see Table 4-1). U.S. EPA (1980d) developed this criterion to protect persons who consume aquatic organisms taken from contaminated water. This AWQC, specified as a concentration for mercury in water, assumes that organisms bioconcentrate contaminants from the water in which they live. It also assumes that exposed persons will consume an average of 6.5 grams of contaminated aquatic organisms per day.

The geometric mean mercury concentration for downstream samples in the Scioto River was 0.13 ug/L; the maximum mercury concentration was 0.2 ug/L. The AWQC for ingestion of aquatic organisms taken from mercury-contaminated water is

0.146 ug/L. Based on this comparison, there appears to be a potential risk from ingestion of contaminated aquatic organisms from the Scioto River. It must be pointed out that this comparison is based on the maximum mercury concentration and may overestimate the potential risk. In fact, mercury was detected in only one of the samples collected from the Scioto River. In addition, no fish tissue samples have been taken to verify the extent of this potential exposure. Therefore, the risk from ingesting contaminated aquatic life appears to be limited.

5.5 DIRECT CONTACT WITH OR INGESTION OF CONTAMINATED SOILS

As discussed in Chapter 3, the major population of concern via exposure to contaminated soils is children who may enter and play at the site. The risk characterization for this scenario focuses on ingesting soil rather than direct contact with soil because ingestion would produce a much greater exposure dose.

Table 3-10 presented estimated most probable and realistic worst case daily doses (for noncarcinogens) and average lifetime doses (for carcinogens) for children who ingest contaminated soils at Bowers Landfill. These doses were calculated using the most probable case ingestion rate (0.1 g/day) and mean concentrations, and worst case ingestion rate (1.0 g/day) and maximum concentrations.

PRC calculated a hazard index (HI) for each noncarcinogenic indicator chemical found in soils at the site. These chemicals are barium, lead, and mercury. In addition, PRC calculated an HI for chlordane. Even though chlordane is considered a carcinogen, U.S. EPA (1986a) has published a reference level that can be used to evaluate noncarcinogenic effects from this chemical. The reference levels used in the calculations are acceptable daily intakes for chronic exposure (AIC). The daily doses (from Table 3-10), AICs (from Table 4-1), and HIs for barium, lead, mercury, and chlordane are presented below.

Chemical	AIC (mg/kg/day)	Worst Case Dose (mg/kg/day)	HI	Probable Case Dose (mg/kg/day)	HI
Barium	5.70 E-02	7.17 E-03	0.13	4.73 E-04	0.01
Lead	1.40 E-03	4.48 E-03	3.20	1.95 E-04	0.14
Mercury ^a	3.00 E-04	1.08 E-05	0.04	6.76 E-07	0.01
Chlordane	5.00 E-05	5.25 E-06	0.11	3.76 E-08	0.01
Total HI			3.48		0.17

^a = assumes alkyl (organic) mercury

As stated in Section 5.1, an HI greater than one indicates a potential risk (U.S. EPA, 1986a). The HI for worst case conditions (maximum concentrations, ingestion of 1.0 g/day) exceeds one. However, it is clear that most of this excess is due to lead. Therefore, based on this analysis, lead concentrations in soil present a potential noncarcinogenic risk under worst case conditions.

In spite of the elevated HI for lead, actual risks from soil ingestion may be limited for two reasons. First, it should be noted that the HI was determined by using the AIC which assumes chronic exposure. The type of exposure evaluated under this scenario (30 ingestions over a 3-year period) is subchronic; however, there is not a subchronic acceptable intake dose available for comparison. Second, the Centers for Disease Control (CDC) (1985) has published clean-up guidelines for lead concentrations in residential soils that it associates with an acceptable risk. The clean-up values are between 500 and 1000 mg/kg, well above the maximum lead concentration found in soils at Bowers Landfill (179 mg/kg). Therefore, the calculated risk may overestimate the actual risk.

Next, PRC calculated the cancer risk associated with the average lifetime exposure doses for the carcinogenic indicator chemicals in soil: chlordane, PAH compounds, and PCBs. The potential cancer risk was calculated from Equation 5-2, using average lifetime doses from Table 3-10 and carcinogenic potency factors from Table 4-1.

It must be noted that U.S. EPA has developed a carcinogenic potency factor for benzo(a)pyrene, but has not published factors for the other carcinogenic PAHs. For these other PAHs, PRC used relative potency factors presented in a document developed by U.S. EPA (1982c). These relative potency factors compare the carcinogenic potency of specific PAHs to the published potency factor for benzo(a)pyrene [$11.5 \text{ (mg/kg/day)}^{-1}$]. U.S. EPA (1982c) acknowledges that some weaknesses and limitations are associated with using relative potency factors. However, PRC believes that a more accurate representation of the potential risk is obtained by this method than by (1) evaluating only the risk for benzo(a)pyrene or (2) summing all the carcinogenic PAH concentrations and using only the potency factor for benzo(a)pyrene.

Table 5-1 presents the potential cancer risks from soil ingestion. These data indicate that under the worst case exposure (maximum soil concentration, 1 gram of soil ingested per day, 10 days per year, for 3 years of exposure), the estimated cancer risk is approximately 3×10^{-6} . That is, for every million people exposed under these conditions, three cases of cancer would be expected. Under the most probable case exposure (mean soil concentration, 0.1 gram of soil ingested per day, 10 days per year, for 3 years of exposure), the estimated cancer risk is approximately 5×10^{-9} (5 cancers per 1 billion people exposed).

Table 5-1 shows that most of the significant carcinogenic risk under worst case exposure is caused by one of the indicator chemicals, PAHs. Chlordane and PCBs contribute little to the total carcinogenic risk.

5.6 INHALATION OF CONTAMINATED AIR

For the exposure scenario involving inhalation of contaminated air, the source of contamination would be either volatilized contaminants from soils and surface water or airborne dust particles originating in the soil. At present, the air contaminant concentrations at Bowers Landfill have not been measured extensively. Limited monitoring with survey instruments during the remedial investigation did not detect concentrations above background levels.

PRC expects the risks due to air emissions from the landfill to be limited for two reasons. First, very few volatile contaminants were detected in any of the environmental media sampled at or near Bowers Landfill. Second, the landfill surface is covered with vegetation. It is unlikely that significant amounts of contaminated dust will be released from the landfill in its current condition.

The release of dust from agricultural areas adjacent to the landfill during plowing or other farming activities is a potential concern. Both farmers and off-site populations are potentially at risk. However, given the soil concentrations of the indicator chemicals, large amounts of dust would have to be generated before air concentrations reached levels of concern. For example, the maximum lead concentration for soil samples collected in agricultural areas was 102 mg/kg (see Table 3-9). If all soil were contaminated at this level, a concentration of 15 mg dust per cubic meter (m^3) of air would be needed to reach the National Ambient Air

TABLE 5-1

ESTIMATED CARCINOGENIC RISK ASSOCIATED WITH
SOIL INGESTION AT BOWERS LANDFILL

<u>Compound</u>	Carcinogenic Potency Factors (mg/kg/day) ⁻¹	<u>Carcinogenic Risk</u>	
		<u>Worst Case^a</u>	<u>Most Probable Case^a</u>
Chlordane	1.30	8 E-09	6 E-11
PAH Compounds			
Benzo(a)anthracene	0.115 ^b	1 E-08	--
Benzo(a)pyrene	11.5	1 E-06	--
Benzo(b)fluoranthracene	3.45 ^b	9 E-07	--
Chrysene	0.115 ^b	2 E-08	--
Dibenzo(a,h)anthracene	11.5 ^b	3 E-07	--
Indeno(1,2,3-c,d)pyrene	0.115 ^b	9 E-09	--
Total PAH Risk		2 E-06	--
PCBs	7.00	7 E-07	5 E-09
Total Carcinogenic Risk		3 E-06	5 E-09

Notes:

- Not calculated, concentrations not greater than background
- a Worst case and most probable case exposure doses are presented in Table 3-10.
- b Carcinogenic potency factors based on relative potency to benzo(a)pyrene as presented in U.S. EPA, 1982c, Errata for the Ambient Water Quality Criterion for the Protection of Human Health: PAH

Quality Standard (NAAQS) for lead, 1.5 ug/m^3 . The NAAQS is calculated as a 3-month average concentration and represents an acceptable exposure level to lead for the general population. While agricultural activities could generate dust concentrations of 15 mg/m^3 for short periods of time, agricultural workers would be exposed only intermittently. Exposure of off-site populations would be much lower, since dust concentrations would decrease during transport. Thus, it is unlikely that significant on-site or off-site exposures to air contaminants could result from agricultural activities adjacent to Bowers Landfill.

5.7 INGESTION OF CONTAMINATED CROPS

No data are available on the contaminant content of crops grown in fields adjacent to Bowers Landfill. However, risks from ingesting these crops should be limited. For most indicator chemicals, soil concentrations were lower in the agricultural field west of the landfill than on the landfill itself. The major exception to this was arsenic, a chemical that does not strongly biomagnify up the food chain.

The extent of any bioconcentration of specific indicator chemicals within crops grown in fields adjacent to the landfill is not known. However, PRC does not anticipate that persons will ingest large amounts of these crops as a specific food source; PRC expects that the amount of crops ingested will form only a very small percentage of a person's diet. Therefore, based on the generally lower contaminant levels measured in the fields adjacent to the landfill and the limited extent of exposure, the risk from ingesting contaminated crops is expected to be limited.

5.8 INGESTION OF CONTAMINATED TERRESTRIAL ANIMALS AND BIRDS

Another potential route of exposure to contaminants released from Bowers Landfill involves ingesting terrestrial animals and birds that have bioaccumulated contaminants. These organisms could bioaccumulate the contaminants from ingesting contaminated water, sediments, and plants, and through contacting soils and sediments at the site. No data are available on the body burdens of these animals, and PRC did not calculate any values because of limited data. PRC believes that due to the low levels of contaminants found at the site or anticipated in these

media, the body burdens in the animals would be low. Therefore the risk associated with ingesting these animals is expected to be limited.

5.9 DIRECT CONTACT WITH OR INGESTION OF CONTAMINATED SURFACE WATERS AND SEDIMENTS BY AQUATIC LIFE

Aquatic life can be exposed to contaminants through direct contact with or ingestion of contaminated surface waters and sediments from the Scioto River. The surface water sampling data identified only one indicator chemicals that was found above background levels near Bowers Landfill -- mercury. To evaluate the potential risk to aquatic life, PRC compared the maximum mercury concentration (Table 3-6) to the Ambient Water Quality Criteria (AWQC) for the protection of aquatic life (Table 4-1). This comparison is shown below.

<u>Chemical</u>	<u>Maximum Concentration (ug/L)</u>	<u>AWQC (ug/L)</u>	
		<u>1-hour</u>	<u>4-day</u>
Mercury	0.2	2.4	0.012

AWQC Ambient Water Quality Criteria for protection of aquatic life

The data show that the maximum mercury concentration exceeds the 4-day (chronic) AWQC, but does not exceed the 1-hour (acute) AWQC. Therefore, there is a potential risk to aquatic life from exposure to mercury in the Scioto River. This comparison may overestimate potential risks, since mercury was found in only a single river water sample and at a concentration equal to the analytical detection limit.

The other exposure scenario for aquatic life involves exposure to contaminated sediments in the Scioto River. To evaluate sediment quality, PRC looked at sediment concentrations that were at least twice background (upstream) levels. Indicator contaminants in this category include chlordane, 4-methylphenol, and barium. PRC compared maximum concentrations of these chemicals to threshold

concentrations published by U.S. EPA (1985b). The threshold concentrations are based on levels that have been measured in ambient surface water sediments.

The only indicator chemical that possibly exceeds a threshold concentration is chlordane. The highest chlordane concentration found in river water sediments, 200 ug/kg, is equal to the threshold concentration. Due to uncertainties associated with establishing threshold values, U.S. EPA (1985b) does not state the direct implications or equaling or exceeding these values. Contaminants in sediment may be released to the overlying surface water. However, PRC believes that due to the low concentrations in the sediment, there is no immediate risk to the aquatic community from exposure to sediments in the Scioto River adjacent to or downstream of Bowers Landfill.

5.10 INGESTION OF CONTAMINATED PLANT LIFE BY TERRESTRIAL ANIMALS AND BIRDS

Plants at or near the site may uptake and potentially bioconcentrate contaminants in the soil. These plants may in turn be ingested by terrestrial animals and birds. The extent of any bioconcentration of specific indicator chemicals within crops grown in fields adjacent to the landfill is not known. Further, PRC has no reliable estimates of the volume or amount of the crops ingested by terrestrial animals and birds.

Soil concentrations of indicator chemicals were generally found to be lower in the adjacent fields than in the landfill itself. As a result, the concentrations of indicator chemicals within crops grown adjacent to the landfill is expected to be low (subject to bioconcentration). PRC anticipates that the risk to terrestrial animals and avian communities will be limited. However, increased risks may result from ingestion by these species of large quantities of crops that have elevated contaminant concentrations due to bioconcentration.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Based on the data reviewed by PRC, it appears that Bowers Landfill may be releasing contaminants to the environment; however, based on results of samples collected during the remedial investigation, these releases do not appear to be extensive. Major potential release mechanisms include migration of leachate to surface water and ground water and movement of contaminated soil due to surface water runoff and periodic flooding of the site. Minor release mechanisms include volatilization of contaminants and releases of dust into the atmosphere.

Over 40 chemical constituents have been identified in ground-water, surface water, soil, and sediment samples collected from Bowers Landfill and from adjacent off-site areas. There is not always a direct relation between what was found on-site and off-site. For example, for several chemicals, concentrations were higher adjacent to the landfill than on the landfill itself. For other chemicals, concentrations on and near the landfill were similar to concentrations in background samples collected in areas not influenced by releases from the landfill. Another complicating factor in evaluating the data is the presence of agricultural lands adjacent to the landfill. Some of the chemicals found have agricultural uses; their presence in samples could be due to this reason, rather than landfilling activities. Nevertheless, PRC believes that the available information does not rule out the landfill as a possible source for many of the chemicals that were detected.

PRC reviewed and evaluated all sampling results and identified 9 indicator chemicals as the focus for this endangerment assessment -- barium, lead, mercury, benzene, chlordane, 4-methylphenol, polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and tetrachloroethene. PRC followed the procedures outlined in U.S. EPA's (1986a) Superfund Public Health Evaluation Manual in selecting these indicator chemicals. Each indicator chemical was selected based on one or more of the following criteria:

- o The chemical was found on or near Bowers Landfill at concentrations above background levels.
- o The chemical was found in several of the environmental media sampled.

- o The chemical is known to be toxic to humans or to aquatic and terrestrial species.
- o The chemical is considered to be representative of other chemicals found at the site. For example, it may produce similar toxic effects or may exhibit similar behavior in environmental systems.

Chapter 1 of the Endangerment Assessment describes this selection process.

PRC reviewed fate and transport information on each of the indicator chemicals. Our results are summarized in Chapter 2. The purpose of this review was to determine how the chemicals might be released from Bowers Landfill and how they would behave in the environment following release. This review showed that three of the indicator chemicals, benzene, 4-methylphenol, and tetrachloroethene, could be released from the landfill by direct volatilization from surface soils. If not released by this mechanism, these chemicals will tend to migrate downward to the water table. Once in ground water, these chemicals should move off-site with the bulk ground-water flow. Benzene, 4-methylphenol, and tetrachloroethene that reach surface water bodies near the landfill are expected to volatilize to the atmosphere.

The remaining organic indicator chemicals (PCBs, PAHs, and chlordane) and the three inorganic indicator chemicals (barium, lead, and mercury) tend to bind strongly to soil or sediment particles. These chemicals are likely to be released from the site only by physical processes that move soil. If these chemicals reach ground water, they are expected to sorb to soil particles or precipitate out of solution. In surface water, the inorganic contaminants (with the possible exception of lead), chlordane, PCBs, and PAHs should sorb to sediment particles and precipitate out of solution. Lead may be somewhat more mobile due to its incorporation in soluble complexes. Mercury and PCBs may volatilize from surface soils, but to a much smaller extent than benzene, 4-methylphenol, and tetrachloroethene.

PRC also reviewed toxicologic data for the 9 indicator chemicals. The results of this review are summarized in Chapter 4. Our review identified benzene as a human carcinogen and chlordane, PAHs, PCBs, and tetrachloroethene as probable human carcinogens. All 9 indicator chemicals are also capable of causing acute and chronic noncarcinogenic health effects in humans. In addition to human health

effects, PRC evaluated the effects of the indicator chemicals on animal species. Of the 9 chemicals, 4 are well documented as toxic to terrestrial and aquatic species. These chemicals are lead, mercury, chlordane, and PCBs.

PRC developed exposure scenarios, identified populations potentially at risk, and estimated the extent of exposure. The results of this process are summarized in Chapter 3. The exposure scenarios for human, aquatic, and terrestrial populations include the following:

- o Ingestion of contaminated ground water
- o Direct contact with or incidental ingestion of contaminated surface water
- o Direct contact with contaminated sediment
- o Ingestion of contaminated aquatic animals from the Scioto River
- o Direct contact with or ingestion of contaminated soil
- o Inhalation of contaminated air
- o Ingestion of contaminated crops
- o Ingestion of contaminated terrestrial animals and birds
- o Direct contact with or ingestion of contaminated surface water and sediments by aquatic life
- o Ingestion of contaminated plant life by terrestrial animals and birds

When sufficient information was available, PRC calculated quantitative exposure estimates for these scenarios. We estimated daily doses and average lifetime doses for exposed persons. These doses are expressed in terms of intake amount of contaminant per kilogram of body weight per day. We also calculated probable case doses, using average (geometric mean) contaminant concentrations, and worst case doses, using maximum concentrations.

PRC then compared the doses to reference levels published by U.S. EPA. We evaluated risks for noncarcinogenic indicator chemicals by calculating a hazard index (HI). The HI is the ratio of the daily dose for a chemical to the acceptable chronic intake level (AIC) for that chemical. The AICs are based on long-term exposure studies and are designed to protect sensitive populations. If the HI for an exposure

scenario exceeds one (that is, if the daily dose exceeds the AIC), there is a potential risk from that exposure.

PRC evaluated the risks for carcinogenic indicator chemicals using carcinogenic potency factors developed by U.S. EPA. When the average lifetime dose is multiplied by the carcinogenic potency factor, the resulting number represents the incremental risk of developing cancer from the exposure. Cancer risk numbers are expressed as probabilities (for example, 10^{-6} , or 1 cancer per million people exposed).

Recent U.S. EPA guidance indicates that the target carcinogenic risks resulting from exposures at a Superfund site may range between 10^{-4} to 10^{-7} (U.S. EPA, 1987a). Thus, remedial alternatives being considered should be able to reduce total potential human carcinogenic risks to levels within this range. U.S. EPA also encourages development of alternatives that eliminate carcinogenic risk where such a remedy is feasible (U.S. EPA, 1987a). Using this range as a baseline, a risk level greater than 10^{-4} is considered to present a "significant" risk, and levels smaller than 10^{-7} are considered insignificant. Risk levels between 10^{-4} and 10^{-7} are within the target range. The use of the terms significant and insignificant are not meant to imply acceptability; however, they are necessary to help put the numerical estimates developed in this endangerment assessment into context.

PRC was not able to calculate dose levels for several exposure scenarios. This is due to the number of assumptions that would be required to make such a calculation. For some of these scenarios, PRC compared concentrations in environmental media to U.S. EPA guidelines and criteria. For example, we compared surface water contaminant concentrations with U.S. EPA health advisory levels for these contaminants. This comparison provides some indication of whether the contaminant levels in the exposure medium may cause adverse health effects. For several other scenarios, data were not available to make this type of comparison. For example, although ingestion of contaminated crops was included as an exposure scenario, contaminant levels in crops have not been measured. In these cases, PRC made qualitative estimates of exposure and risk.

PRC identified potentially significant risks to human, aquatic, and terrestrial populations for several exposure scenarios in Chapter 5 of this report. These

potentially significant risks are listed in Table 6-1. The findings for each exposure scenario are summarized below.

The first exposure scenario involves ingestion of contaminated ground water. Samples taken from monitoring wells downgradient of Bowers Landfill indicate that contaminants are present in both the upper and lower aquifers. At present, no private drinking water wells are located downgradient between the landfill and the Scioto River. Further, data presented in Chapter 3 shows that the City of Circleville wellfield, located **non responsive**, has not been affected by releases from the landfill. However, if contaminated water from the upper or lower aquifer is used as a future drinking water source **non responsive**, it would present a limited risk to human health based on the following analysis.

PRC performed a quantitative analysis of the risk by calculating most probable case (mean concentration) and worst case (maximum concentration) daily doses and average lifetime doses for persons drinking 2 liters of contaminated ground water per day over a 70-year lifetime. We identified, under the worst case, a potential noncarcinogenic risk from barium ($HI = 1.04$). PRC also identified a potential carcinogenic risk due to benzene under both scenarios. The incremental cancer risk for lifetime ingestion of ground water under worst case exposure conditions was 9×10^{-6} . That is, for every 1 million people exposed under these conditions, 9 cases of cancer would be expected. The probable case risk estimate was 1×10^{-6} . These risks slightly exceed the target range of 10^{-4} to 10^{-7} .

PRC's analysis may overestimate potential risks for ground-water ingestion for two reasons. First, the greatest risks were estimated from maximum concentrations of these indicator chemicals in ground water; average ground-water concentrations showed a lower risk. Second, PRC considers the likelihood of exposure by this scenario to be small. The area between Bowers Landfill and the Scioto River is regularly flooded. Therefore, there is a low probability that ground water in this area would be used as a drinking water source in the future.

The second exposure scenario considers direct contact with or ingestion of contaminated surface water from the Scioto River or the drainage ditches and quarries near Bowers Landfill. Exposure could occur if people waded in or fell into

TABLE 6-1
SUMMARY OF POTENTIALLY SIGNIFICANT RISKS
IDENTIFIED FOR BOMERS LANDFILL
(Page 1 of 2)

<u>Exposure Route</u>	<u>CA/NCA</u> ¹	<u>Contaminants</u>	<u>Risk Assessment</u>	<u>Comments</u>	<u>Reference</u>
1. Ingestion of Ground Water	NCA	Barium	Hazard Index ² = 1.04	While based on the maximum barium concentration, the hazard index only slightly exceeds unity. Therefore, the actual noncarcinogenic risk via this scenario is probably very small.	5.1
	CA	Benzene	Incremental Carcinogenic risk = 9E-06 (worst case), 1E-06 (probable case)	The incremental carcinogenic risks for benzene are within the target range of 10 ⁻⁶ to 10 ⁻⁷ (see footnote No. 3).	
2. Ingestion of Surface Water	CA	PCBs	Maximum PCB concentration in the drainage ditches (2.6 ug/l) exceeds the ambient water quality criteria (AWQC) for consumption of drinking water alone corresponding to a 10 ⁻⁶ cancer risk (0.012 ug/L).	The AWQC for PCBs used here assumes a lifetime exposure while this scenario assumes infrequent incidental ingestion, therefore, this risk assessment overestimates the actual risk.	5.2
3. Ingestion of Aquatic Animals	NCA	Mercury	The maximum mercury concentration (0.2 ug/L) exceeds the AWQC based on ingestion of aquatic animals alone (0.1465 ug/L).	Tissue samples have not been taken to verify the extent of this exposure. Further, average mercury concentrations were below the AWQC and mercury was found in only one surface water sample from the Scioto River. Thus, this risk is limited.	5.4

TABLE 6-1 (continued)

Exposure Route	CA/NCA ¹	Contaminants	Risk Assessment	Comments	Reference
4. Ingestion of Soils	NCA	Lead	Hazard Index = 3.20	This hazard index may overestimate the actual risk because it assumes both the maximum lead concentration and a worst case soil ingestion rate. Further, lead levels in on-site soils are below CDL guidelines for residential areas.	5.5
	CA	Total PAHs ⁴	Incremental Carcinogenic Risk = 2E-06	These two risks may overestimate the actual risk because they are based on maximum concentrations and a worst case soil ingestion rate. See also Footnote No. 3.	
		PCBs	Incremental Carcinogenic Risk = 7E-07		
5. Direct Contact with Surface Water by Aquatic Animals	NCA	Mercury	Maximum mercury concentration (0.2 ug/L) exceeds the 4-day AWQC for protection of aquatic life (0.012 ug/L).	Actual risk may be negligible based on average mercury concentrations. Further mercury was found in only one surface water sample from the Scioto River.	5.9

Notes:

1 CA = Carcinogenic
NCA = Noncarcinogenic

2 The hazard index (HI) is calculated as the ratio of exposure dose to acceptable dose; an HI > 1 indicates a potentially significant risk.

3 EPA guidance (U.S. EPA, 1987a) described a carcinogenic risk target range (10^{-4} to 10^{-7}). Risks greater than 10^{-4} are considered "significant", while risks $< 10^{-7}$ are considered insignificant. Risks between 10^{-4} and 10^{-7} are within the target range, their significance will in general reflect site specific factors.

4 PRC considered the following PAHs: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene. The incremental carcinogenic risk for total PAHs was calculated by multiplying the maximum concentration of each PAH other than benzo(a)pyrene by a relative potency factor to benzo(a)pyrene (U.S. EPA, 1982c). The adjusted concentrations were then summed along with the concentration of benzo(a)pyrene itself and, finally, multiplied by the carcinogenic potency factor for benzo(a)pyrene.

these surface water bodies. In evaluating this scenario, PRC focused on incidental ingestion of surface water, because this should produce a greater dose than direct contact.

PRC compared maximum surface water concentrations with U.S. EPA guidelines and criteria for acute or short-term exposure. When short-term guidelines were not available, PRC compared maximum concentrations with guidelines for long-term or chronic exposure. Of the indicator chemicals found in surface water, only PCBs exceeded a guideline. The maximum PCB concentration of 2.6 ug/L was higher than the long-term ambient water quality criterion (AWQC) of 0.0126 ug/L. Although this indicates a potential risk, the AWQC is based on lifetime exposure to 2 liters of contaminated water per day. Thus, the AWQC is not directly applicable to the infrequent exposure and small amounts of water ingested under this exposure scenario. Risks from ingesting contaminated surface water are limited.

The third exposure scenario involves direct contact with contaminated sediments. As with the previous scenario, exposure should be limited to individuals who wade through or fall into drainage ditches or the Scioto River. PRC identified a very limited risk from this scenario because (1) exposure is not expected to be frequent and (2) none of the indicator chemicals found in sediments easily transfers from sediment particles to the skin.

PRC identified a limited risk for the fourth exposure scenario, ingestion of aquatic animals from the Scioto River. Only one indicator chemical, mercury, was found above background (upstream) concentrations in the Scioto River near Bowers Landfill. The maximum mercury concentration in river water (0.2 ug/L) slightly exceeded the AWQC for ingestion of aquatic life (0.146 ug/L); the average mercury concentration (0.13 ug/L) was below the AWQC. This AWQC was developed by U.S. EPA to protect persons who consume 6.5 grams per day of aquatic organisms taken from mercury-contaminated water. PRC considers the risk to be limited because mercury was found in only a single river water sample and because the maximum concentration only slightly exceeded the AWQC.

The fifth scenario considers direct contact with or ingestion of contaminated soils. PRC focused this scenario on the most sensitive population that could be exposed -- children who may play at Bowers Landfill. PRC calculated daily and

average lifetime doses for indicator chemicals found in soils. PRC assumed that children between the ages of 4 to 6 would be exposed. We also assumed that these children would ingest soil 10 times per year over a 3-year period. Under worst case conditions, we assumed that the children would ingest 1 gram of soil per day at the maximum concentration; as a most probable case, we assumed an ingestion rate of 0.1 gram of soil per day at the average concentration.

PRC identified a potential noncarcinogenic risk under the worst case scenario for exposure to lead ($HI = 3.20$). This risk was estimated by comparing the calculated dose with acceptable chronic intake levels for lead published by U.S. EPA. This comparison may overestimate potential risks, because the exposure conditions evaluated (30 ingestions of soil over a 3-year period) represent subchronic, rather than chronic, exposure. However, U.S. EPA has not developed an acceptable subchronic intake level for lead. Further, maximum lead concentrations in soils at Bowers Landfill (179 mg/kg) are well below guidelines recommended by the Centers for Disease Control to protect children in residential areas (500 mg/kg to 1000 mg/kg).

PRC also identified an incremental carcinogenic risk of 3×10^{-6} under the realistic worst case exposure. That is, for every 1 million children exposed under these conditions, 3 cancer cases are expected. Most of the incremental carcinogenic risk was attributed to PAHs, with only minor contributions from PCBs and chlordane. This risk falls within the target range of 10^{-4} to 10^{-7} . As noted previously, PAHs found near Bowers Landfill may be due in part to other activities that produce these chemicals since PAHs were also found in the background samples. Worst case risks calculated under this scenario may overestimate actual risks because they are based on maximum soil concentrations and a worst case soil ingestion rate. Most probable case carcinogenic risks for soil ingestion were 5×10^{-9} .

The sixth scenario involves inhalation of contaminated air. No air sampling data have been collected at Bowers Landfill, although limited air monitoring has occurred. PRC concluded that a very limited potential risk exists for three reasons. First, very few volatile organic contaminants were found in surface water or soils at the site. Thus, direct releases of these chemicals to air should be minimal. Second, most of the landfill surface is covered with vegetation. This

should prevent air releases of significant amounts of contaminated dust. Finally, agricultural activities in the field west of the landfill could potentially generate contaminated dust. However, contaminant concentrations in soil are relatively low; substantial amounts of dust would have to be generated for air concentrations of contaminants to reach levels of concern.

There are no site-specific data for the seventh exposure scenario, ingestion of contaminated crops. However, PRC concluded that the risk for this scenario is very limited. Soil contaminant concentrations were generally higher on the landfill than in adjacent fields where crops would be grown. Further, PRC does not expect that persons will ingest large amounts of these crops as a specific food source.

The eighth exposure scenario is ingestion of contaminated terrestrial animals and birds. No samples were taken to determine body burdens in animals and birds near Bowers Landfill. However, due to the low contaminant levels found at the site, body burdens are expected to be low. Therefore, PRC expects that exposure under this scenario would pose a limited risk.

The ninth exposure scenario concerns aquatic populations exposed to contaminated sediment and surface water in the Scioto River. PRC determined that there is a potential risk to aquatic life exposed to mercury in river water. The maximum mercury concentration (0.2 ug/L) exceeded the 4-day (chronic) AWQC for aquatic life (0.012 ug/L). This comparison may overestimate potential risks, since mercury was found in only one river water sample.

PRC also evaluated exposure to contaminated sediments under this scenario. We compared maximum sediment concentrations to threshold concentrations published by U.S. EPA. Chlordane was the only indicator chemical to equal a threshold concentration. U.S. EPA does not state the direct implications of equaling or exceeding these threshold values. However, PRC believes that the sediment concentrations present little immediate risk to the aquatic community in the Scioto River adjacent to or downstream of Bowers Landfill.

The final exposure scenario considers ingestion of contaminated plants by terrestrial animals and birds. There are no site-specific data for this exposure scenario. Further, PRC has no reliable estimates of the amounts of contaminated

plants that could be ingested by animals and birds near the site. PRC expects the risks to animals and birds under this scenario to be low. However, increased risks could result if these species ingest large amounts of plants that have elevated contaminant levels due to bioconcentration.

In interpreting the risks presented in this report, two limiting factors must be considered. First, some of the potential exposure scenarios have a low probability of occurring. For example, exposure to contaminated ground water will occur only if drinking water wells are placed between Bowers Landfill and the Scioto River. PRC considers this unlikely, since the area is regularly flooded. Finally, some of the indicator chemicals evaluated in this endangerment assessment may have come from sources other than the landfill. This is particularly true of chlordane, which may have been used as a pesticide in agricultural areas near the landfill.

Subject to these limitations, PRC concludes that under several exposure scenarios, releases from Bowers Landfill may present a risk to human health and the environment. Carcinogenic risks for ingestion of ground water and soil by humans fall within the target risk range of 10^{-4} to 10^{-7} . There are also potential noncarcinogenic risks for these exposure scenarios, since hazard indices exceed one. Incidental ingestion of surface water and ingestion of aquatic animals taken from the Scioto River could also pose potential risks to human populations. Aquatic organisms are also potentially at risk due to contaminant concentrations in the Scioto River.

CHAPTER 7

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TABLE A-4 (Continued)
BOWERS LANDFILL
SEDIMENT SAMPLES (ROUNDS 1 AND 2)

Sample Location:	18(1)	18(2)	19(1)	19(2)	20(1)	20(2)	21(1)	21 (1-DUP)	21(2)	21 (2-DUP)	22(1)	22 (1-EPA)	22(2)
INORGANIC COMPOUNDS (mg/kg)													
Aluminum	7320 *	5720 *E	4460 *	4280 *E	6550 *	5460 E	8410 *	9750 *	8320 E*	7800 E*	4910 *	8140	3160 E*
Arsenic	12 N*	7.2 N	(2.2) S+N*	(3.7) N	7.8 *N	7.1 N	7.9 MN*	7 S+N*	12 N	11 N	21 N*	57 *	5.7 N
Barium	118	108 E	72	71 E	92	99 E	149	157	168 E	(151) E	100	312	(75) E
Beryllium	(0.40)						(0.58)	(0.60)					
Cadmium		2.1			1.7				(3.6)			5.6	
Calcium	21800	26800 E	23800	32000 E	25300	24900 E	27200	27700	35300 E	32800 E	29000	31500	25500 E
Chromium	12	16	13	15	19	14	25	26	20	17	14	20	12
Cobalt	(8.4) E	(4.3)	(5.4) E	(2.5)	(7.7) E	(3.5)	(10) E	(11) E			(5.6) E	(7.9)	
Copper	22 E	21 E	19 E	16 E	26 E	20 E	38 E	38 E	24 E	23 E	24 E	22	12 E
Iron	21200	15000 *E	12100	13700 *E	17300	16100 E*	24400	26100	24100 E*	23400 E*	19600	22900 *	10800 E*
Lead	26	38	28	28	39	35	101	98	48	49	31	39	41 *
Magnesium	9790	11000 E	8680	11200 E	9840	9130 E	11300	11700	12400 E	11600 E	8150	11400	8320 E
Manganese	554	336 *E	194	282 E*	266	276 E*	531	580	487 E*	458 E*	342	374 N	266 E*
Mercury	0.17 N	0.40	0.14 N	0.46	0.31 N	0.37	0.12 N	0.19 N	1.1	0.45	0.31 N	0.44 *N	0.52
Nickel	31	24	14	18	25	30	31	35	36	37	21	19	19
Potassium	(749)		(559)		(1580)		(1210)	(1150)			(733)	(1570)	
Silver		4.2	(2.3)		(2.0)	(3.0)	(1.8)		8.0		(2.1)		
Sodium					(1030)		(823)					(812)	
Thallium													
Vanadium	20 E	(12)	(12) E	(8.7)	19 E	(9.4)	22 E	25 E	(6.5)	(6.6)	(13) E	25	(2.5)
Zinc	95	177 *E	113	139 E*	174	189 E*	215	224	219 E*	204 E*	142	227	132 E*

Notes: Blank spaces in table indicate that compound was analyzed for but not detected

(1) Round 1 samples collected in February 1987.

(2) Round 2 samples collected in April 1987.

(DUP) Dames & Moore field duplicate sample result.

(EPA) U.S. EPA split sample result.

B Indicates that compound was found in blank samples.

J Indicates an estimated value; compound was found in sample at concentrations below the contract required detection limit.

(XX) See note for J above.

E Indicates that concentration is estimated due to presence of interference during analysis.

* Indicates that laboratory duplicate analysis is not within CLP control limits.

N Indicates that spike sample recovery is not within CLP control limits.

S Indicates that concentration was determined by method of standard additions.

S+ Indicates that concentration as determined by standard additions but correlation coefficient was less than 0.995.

M Indicates that duplicate injection results exceed CLP control limits.

II Laboratory that analyzed Dames & Moore samples reportedly could not distinguish between these two isomers.

TABLE A-4 (Continued)
BOWERS LANDFILL
SEDIMENT SAMPLES (ROUNDS 1 AND 2)

Sample Locations:	23(1)	23(2)	24(1)	24(2)	25(1)	25(2)	26(1)	26(2)	27(1)	27(2)	28(1)	28 (1-DUP)	28(2)
ORGANIC COMPOUNDS (ug/kg)													
Volatiles													
Chloroform								7.1 J					
Methylene Chloride	23 B	15 B	9.4 B	66 B	17 B	150 B	18 B	61 B	36 B	23 B	2.8 J	2.8 J	32
Toluene						2.6 J					20 B	22 B	
Acetone	24 B	16 JB	8.1 JB	15 B	12 JB	21 B	14 JB	38 B	19 B	19 B	20 B	12 JB	20 J
Semi-Volatiles													
Phenol		79 J				120 J		76 J					
Benzoic Acid													84 J
4-Methylphenol		670		120 J	660	1200		330 J		150 J			
Fluoranthene	130 J	440 J	49 J		52 J	950	130 J	160 J	200 J		140 J	240 J	670 J
Bis(2-Ethylhexyl)Phthalate	300 J	1100 B	53 J	79 JB	47 J	170 JB	110 J	110 JB	190	78 J	140 J	160 J	150 JB
Butyl Benzyl Phthalate		79 J											
Di-N-Butyl Phthalate													
Di-N-Octyl Phthalate													
Benzo(a)anthracene		200 J				400 J	63 J		120 J		81 J	130 J	290 J
Benzo(a)pyrene	68 J	180 J				400 J	86 J		160 J		100 J	150 J	350 J
Benzo(b)fluoranthene-II	130 J	480 J	75 J		76 J	1000	180 J		330 J		220 J	360 J	760
Benzo(k)fluoranthene-II	130 J	480 J	75 J		76 J	1000	180 J		330 J		220 J	360 J	760
Chrysene	100 J	260 J				710 J	100 J	95 J	170 J		110 J	200 J	370 J
Acenaphthylene						63 J							
Anthracene						53 J							
Benzo(ghi)perylene						290 J			130 J			110 J	
Fluorene													
Phenanthrene	68 J	220 J				370 J	63 J	70 J	100 J			120 J	380 J
Dibenzo(a,h)anthracene						92 J							
Indeno(1,2,3-cd)pyrene						270 J			98 J			100 J	
Pyrene	150 J	440 J	53 J		80 J	800	130 J	130 J	220 J		140 J	220 J	620 J
Pesticides and PCBs													
Chlordane													
Arochlor-1248									2300		420	520	

TABLE A-4 (Continued)
BOWERS LANDFILL
SEDIMENT SAMPLES (ROUNDS 1 AND 2)

Sample Location:	23(1)	23(2)	24(1)	24(2)	25(1)	25(2)	26(1)	26(2)	27(1)	27(2)	28(1)	28 (1-DUP)	28(2)
INORGANIC COMPOUNDS (mg/kg)													
Aluminum	6710 *	5600 E*	4240 *	4460 *	2820 *	4260 E*	6310 *	5300 *	8840 *	2820 *	10500 *	12100 *	7320 *
Arsenic	5.18 *SN	6.0 M	5.9 N*	3.6 M	6.9 N*	7.4 M	7.4 N*	6.2 M	7.2 N*	4.0 M	8.3 S+N*	13 N*	6.3 M
Barium	133	115 E	72	88	[35]	63 E	104	141	136	73	151	171	179
Beryllium				[0.49]				[0.59]	[0.38]	[0.50]	[0.90]	[0.85]	[0.74]
Cadmium				4.2		1.9		2.9		2.9		1.8	[1.8]
Calcium	39500	47200 E	91000	77100	93000	110000 E	48100	26500	33700	82500	10100	11200	13900
Chromium	19	15	5.4	6.5	4.2	5.2	9.9	9.2	13	[2.2]	16	18	11
Cobalt	[8.5] E	[2.1]	[5.8] E	[5.2]	[4.2] E	[4.4]	[5.9] E	[4.5]	[12] E	[4.7]	[9.1] E	[11] E	[5.6]
Copper	27 E	20 E	18 E	14 E	12 E	18 E	22 E	18 E	36 E	14 E	45 E	49 E	22 E
Iron	18600	18400 E*	15600	15300 *	12200	17300 E*	20800	12700 *	26600	11500 *	25400	30200	17200 *
Lead	37	37	9.0	17 *	9.5	20	38	79	104	34	42	48	45 *
Magnesium	15500	19500 E	30400	21400	22400	35300 E	13900	11000	13800	27300	5310	6230	6640
Manganese	425	40E E*	367	665 *	247	416 E*	265	244 *	552	476 *	291	392	365 *
Mercury	0.2 M	0.59		0.76				1.4			0.26 M	0.21 M	
Nickel		27	19	18	13	26	28	15	30	15	43	48	28
Potassium	[1300]								[1050]		[1200]	[1200]	
Silver	[1.6]		[1.2]										
Sodium	[1000]				[476]				[549]				
Thallium						[0.84]				[0.63]			[0.90]
Vanadium	17 E	[10]	14	[13]	[10]	[13]	16 E	[12]	25 E	[9.9]	26 E	30 E	[11]
Zinc	177	158 E*	67	69 *	58	81 E*	119	159	163	65 *	415	483	191

Notes: Blank spaces in table indicate that compound was analyzed for but not detected

(1) Round 1 samples collected in February 1987.

(2) Round 2 samples collected in April 1987.

(DUP) Dames & Moore field duplicate sample result.

(EPA) U.S. EPA split sample result.

B Indicates that compound was found in blank samples.

J Indicates an estimated value; compound was found in sample at concentrations below the contract required detection limit.

[xx] See note for J above.

E Indicates that concentration is estimated due to presence of interference during analysis.

* Indicates that laboratory duplicate analysis is not within CLP control limits.

M Indicates that spike sample recovery is not within CLP control limits.

S Indicates that concentration was determined by method of standard additions.

S+ Indicates that concentration as determined by standard additions but correlation coefficient was less than 0.995.

M Indicates that duplicate injection results exceed CLP control limits.

II Laboratory that analyzed Dames & Moore samples reportedly could not distinguish between these two isomers.

TABLE A-4 (Continued)
BOWERS LANDFILL
SEDIMENT SAMPLES (ROUNDS 1 AND 2)

Sample Location:		29(1)	29(2)	29 (2-DUP)	29 (2-EPA)
ORGANIC COMPOUNDS (ug/kg)					
Volatiles					
Chloroform					
Methylene Chloride		25 B	60 B	120 B	
Toluene					
Acetone		9.8 JB	17 B	15 B	
Semi-Volatiles					
Phenol					
Benzoic Acid					
4-Methylphenol					
Fluoranthene		160 J			120 J
Bis(2-Ethylhexyl)Phthalate		68 J	170 J	72 JB	1090
Butyl Benzyl Phthalate					
Di-N-Butyl Phthalate					127 J
Di-N-Octyl Phthalate					
Benzo(a)anthracene		78 J			
Benzo(a)pyrene		94 J			
Benzo(b)fluoranthene-II		200 J			
Benzo(k)fluoranthene-II		200 J			
Chrysene		110 J			
Acenaphthylene					
Anthracene					
Benzo(ghi)perylene		78 J			
Fluorene					
Phenanthrene		68 J			
Dibenzo(a,h)anthracene					
Indeno(1,2,3-cd)pyrene		62 J			
Pyrene		140 J			128 J
Pesticides and PCBs					
Chlordane					
Arochlor-1248		1600			550

TABLE A-4 (Continued)
BOWERS LANDFILL
SEDIMENT SAMPLES (ROUNDS 1 AND 2)

Sample Location:	29(1)	29(2)	29 (2-DUP)	29 (2-EPA)
INORGANIC COMPOUNDS (mg/kg)				
Aluminum	10700 *	6740 *	7890 *	16400
Arsenic	16 N*	4.5 N	7.4 N	16 S+N
Barium	205	179	204	227 E
Beryllium	[0.37]	[0.67]	[2.72]	[0.8]
Cadmium			3.5	2.9
Calcium	9620	8990	10500	10800
Chromium	15	11	12	21 *
Cobalt	14 E	[6.1]	[11]	14
Copper	31 E	20 E	20 E	30
Iron	29300	16000 *	19700 *	36200 E
Lead	25	23 *	26 *	41
Magnesium	5470	4480	4490	6530 E
Manganese	854	658 *	846 *	1280 E
Mercury		1.0		0.1
Nickel	37	23	25	42
Potassium	[1120]			2020
Silver				
Sodium				
Thallium		[0.93]		
Vanadium	28 E	[13]	[18]	41
Zinc	125	91 *	107 *	150 E

Notes: Blank spaces in table indicate that compound was analyzed for but not detected

(1) Round 1 samples collected in February 1987.

(2) Round 2 samples collected in April 1987.

(DUP) Dames & Moore field duplicate sample result.

(EPA) U.S. EPA split sample result.

B Indicates that compound was found in blank samples.

J Indicates an estimated value; compound was found in sample at concentrations below the contract required detection limit.

[XX] See note for J above.

E Indicates that concentration is estimated due to presence of interference during analysis.

* Indicates that laboratory duplicate analysis is not within CLP control limits.

N Indicates that spike sample recovery is not within CLP control limits.

S Indicates that concentration was determined by method of standard additions.

S+ Indicates that concentration as determined by standard additions but correlation coefficient was less than 0.995.

M Indicates that duplicate injection results exceed CLP control limits.

II Laboratory that analyzed Dames & Moore samples reportedly could not distinguish between these two isomers.

TABLE A-5

**SUMMARY OF PREVIOUSLY REPORTED SAMPLING AND ANALYSIS DATA
DOWERS LANDFILL - CIRCLEVILLE, OHIO
SOURCE: BURGESS & NIPLE, 1981
(Concentrations in mg/L unless otherwise noted.)**

Parameter	U.S. EPA Surface Water Sampling Locations 7/9/80(1)					Burgess & Niple Sampling Locations(1)			
	A	B	C	D	E	A 7/17/81	A 8/20/81	A 9/15/81	F 7/17/87
1. Indicator Parameters									
Chloride	NA	NA	NA	NA	NA	31	NA	17	60
Chemical oxygen demand	NA	NA	NA	NA	NA	32	35	34	190
Conductivity (μhos)	NA	NA	NA	NA	NA	NA	440	570	NA
Hardness (as CaCO ₃)	NA	NA	NA	NA	NA	320	NA	NA	460
Nitrate (as N)	NA	NA	NA	NA	NA	0.13	NA	NA	0.15
pH (lab-S.U.)	NA	NA	NA	NA	NA	7.5	7.4	7.1	7.8
2. Inorganic Parameters									
Antimony	NA	NA	NA	NA	NA	NA	NA	NA	ND
Arsenic	NA	NA	NA	NA	NA	NA	NA	NA	ND
Barium	NA	NA	NA	NA	NA	NA	NA	NA	0.410
Beryllium	NA	NA	NA	NA	NA	NA	NA	NA	ND
Cadmium	NA	NA	NA	NA	NA	NA	ND	NA	0.009
Chromium	NA	NA	NA	NA	NA	NA	NA	NA	0.04
Copper	NA	NA	NA	NA	NA	NA	NA	NA	0.03
Cyanide	NA	NA	NA	NA	NA	NA	NA	NA	0.03
Iron	NA	NA	NA	NA	NA	1.4	0.18	6.20	1.5
Lead	NA	NA	NA	NA	NA	NA	NA	NA	0.015
Mercury	NA	NA	NA	NA	NA	NA	NA	NA	ND

NA = parameter not analyzed for.

ND = parameter analyzed for but not detected.

B = parameter detected in laboratory blank.

(1) Sampling locations on Drawing 1-3.

Source: Dames & Moore, 1987a

TABLE A-5 (Continued)

Parameter	U.S. EPA	Surface	Water	Sampling	Locations	7/9/80(1)	Burgess & Niple Sampling Locations(1)			
	A	B	C	D	E		A 7/17/81	A 8/20/81	A 9/15/81	F 7/17/87
Nickel	NA	NA	NA	NA	NA	NA	NA	ND	NA	0.01
Selenium	NA	NA	NA	NA	NA	NA	NA	NA	NA	ND
Silver	NA	NA	NA	NA	NA	NA	NA	NA	NA	ND
Thallium	NA	NA	NA	NA	NA	NA	NA	ND	NA	0.003
Zinc	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.05
3. Organic Parameters										
Benzene(2)	ND	ND	ND	0.012	ND	ND	ND	NA	NA	NA
Diethyl phthalate (2)	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA
Ethylbenzene(2)	ND	ND	ND	0.12	2.40	ND	NA	NA	NA	NA
Ethylbenzene(3)	ND	NA	NA	NA	NA	NA	ND	ND	ND	ND
Methylene chloride(2)	ND	NA	NA	NA	NA	ND(B)	NA	NA	NA	NA
Mixed xylenes(2)	ND	NA	NA	NA	NA	NA	ND	ND	ND	ND
Naphthalene(2)	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA
Phenols(2)	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA
Phenols(4)	NA	NA	NA	NA	NA	0.0011	NA	0.05	0.081	0.081
Toluene(2)	ND	ND	0.04	1.10	1.80	ND	NA	NA	NA	NA
Toluene(3)	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND
Trichloroethylene(2)	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA
1,2-Trans-dichloroethylene(2)	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA
2,4-Dimethylphenol(2)	NA	NA	NA	NA	NA	0.15	NA	NA	NA	NA

NA = parameter not analyzed for.

ND = parameter analyzed for but not detected.

B - parameter detected in laboratory blank.

(1) Sampling locations on Drawing 1-3.

(2) Gas chromatography/mass spectrometry.

(3) Gas chromatography - liquid extraction.

(4) Spectrophotometry.

Source: Dames & Moore, 1987a

TABLE A-5 (Continued)

Parameter	Burgess & Niple Sampling Locations (1)								
	MW-1 7/17/81	MW-1 8/20/81	MW-1 9/15/81	MW-2 7/17/81	MW-2 8/20/81	MW-2 9/15/81	MW-3 7/17/81	MW-3 8/20/81	MW-3 9/15/81
1. Indicator Parameters									
Chloride	25	NA	15	38	NA	26	64	NA	13
Chemical oxygen demand	56	88	159	440	670	410	470	320	120
Conductivity (μ hos)	NA	500	670	NA	850	1000	NA	580	530
Hardness (as CaCO_3)	400	NA	NA	500	NA	NA	580	NA	NA
Nitrate (as N)	0.02	NA	NA	0.36	NA	NA	0.11	NA	NA
pH (lab-S.U.)	7.2	7.3	7.1	6.5	6.6	6.2	6.9	6.9	6.9
2. Inorganic Parameters									
Antimony	ND	NA	NA	ND	NA	NA	NA	NA	NA
Arsenic	ND	NA	NA	ND	NA	NA	NA	NA	NA
Barium	0.13	NA	NA	0.41	NA	NA	NA	NA	NA
Beryllium	ND	NA	NA	ND	NA	NA	NA	NA	NA
Cadmium	0.017	ND	NA	0.01	0.006	NA	NA	ND	NA
Chromium	0.009	NA	NA	0.017	NA	NA	NA	NA	NA
Copper	0.014	NA	NA	0.015	NA	NA	NA	NA	NA
Cyanide	ND	NA	NA	ND	NA	NA	NA	NA	NA
Iron	1.5	0.06	0.85	40	0.90	100	0.43	0.26	3.90
Lead	0.02	NA	NA	0.01	NA	NA	NA	NA	NA
Mercury	ND	NA	NA	ND	NA	NA	NA	NA	NA

NA = parameter not analyzed for.

ND = parameter analyzed for but not detected.

B = parameter detected in laboratory blank.

(1) Sampling locations on Drawing 1-3.

(2) Gas chromatography/mass spectrometry.

(3) Gas chromatography - liquid extraction.

(4) Spectrophotometry.

Source: Dames & Moore, 1987a

Wood, P.R., and others, 1985. Anaerobic Transformation, Transport and Removal of Volatile Chlorinated Organics in Ground Water, in Ground Water Quality (Ward, C.H., and others, eds.). John Wiley and Sons, New York.

APPENDICES

- Appendix A Analytical Results --
 Bowers Landfill**
- Appendix B Definitions of Fate and
 Transport Processes**
- Appendix C Glossary of Toxicological
 Terminology**
- Appendix D Calculation of Geometric Mean
 Concentrations for Indicator Chemicals**

APPENDIX A
ANALYTICAL RESULTS FOR
BOWERS LANDFILL

Table A-1	Soil Samples (Round 1)
Table A-2	Ground-Water Samples (Rounds 1, 2, and 3)
Table A-3	Surface Water Samples (Rounds 1 and 2)
Table A-4	Sediment Samples (Rounds 1 and 2)
Table A-5	Summary of Previously Reported Sampling and Analysis Data (U.S. EPA, Burgess & Niple)
Figure A-1	Locations of Samples Collected by U.S. EPA and Burgess & Niple
Table A-6	Summary of Previously Reported Sampling and Analysis Data (Ohio EPA)
Figure A-2	Locations of Samples Collected by Ohio EPA
Table A-7	Supplemental Soil Sample Results

TABLE A-1
BOWERS LANDFILL
SOIL SAMPLES

Sample Location:	5	6	7	10	11	30	31	32	33	34	35	35(EPA)	36
ORGANIC COMPOUNDS (ug/kg)													
Volatiles													
Acetone		17 B	7.0 JB	18 B		82 B	14 B	31 B	7.8 JB	10 JB		21 B	12 JB
Chloroform												4 JB	
Bromomethane										2.3 J			
Methylene Chloride	34 B	49 B	11 B	150 B	120 B	42 B	14 B	12 B	3.4 JB	7.4 B	20 B	12 B	12 B
Toluene												2 JB	
Semi-Volatiles													
Benzoic Acid												38 J	
Acenaphthene													
Fluoranthene	160 J	65 J	83 J	120 J	360 J	63 J	100 J	130 J	160 J	54 J	96 J	280 JB	170 J
Naphthalene												6 J	
Bis(2-Ethylhexyl)Phthalate	130 J	45 J		120 J	180 J				70 J	160 J	420 J		130 J
Butyl Benzyl Phthalate													
Di-N-Butyl Phthalate					55 J					50 J		48 J	
Di-N-Octyl Phthalate												270 JB	
Diethylphthalate												31 JB	
Benzo(a)anthracene	88 J		44 J	58 J	150 J		48 J	79 J	74 J	54 J	74 J	130 J	85 J
Benzo(a)pyrene	110 J			83 J	220 J		75 J	91 J	120 J	77 J			100 J
Benzo(b)fluoranthene-II	97 J	85 J	95 J	170 J	460		160 J	170 J	270 J	170 J			240 J
Benzo(k)fluoranthene-II	74 J	85 J	95 J	170 J	460		160 J	170 J	270 J	170 J			240 J
Chrysene	140 J	85 J	59 J	100 J	220 J		70 J	100 J	140 J	73 J	130 J	210 J	130 J
Acenaphthylene													
Anthracene													
Benzo(ghi)perylene				50 J	160 J		75 J	91 J	100 J				77 J
Fluorene													
Phenanthrene	74 J			54 J	140 J	54 J	53 J	66 J	99 J		57 J	120 J	72 J
Dibenzo(a,h)anthracene													
Indeno(1,2,3-cd)pyrene				50 J	140 J		57 J	66 J	95 J				60 J
Pyrene	160 J	77 J	95 J	100 J	260 J	110 J	100 J	120 J	160 J	73 J	130 J	420 B	140 J
Dibenzofuran												4 J	
2-Methylnaphthalene												4 J	
Pesticides and PCBs													
Beta-BHC					22								
Dieldrin			20		27								
Chlordane					110							210	
Arochlor-1242												600	
Arochlor-1248							1200			3600	350		380
Arochlor-1254									300				

A-1

TABLE A-1 (Continued)
BOWERS LANDFILL
SOIL SAMPLES

Sample Location:	5	6	7	10	11	30	31	32	33	34	35	35(EPA)	36
INORGANIC COMPOUNDS (mg/kg)													
Aluminum	13800	13700	8690	13800	14100	21100	20200	14500	19800	2400	20700	18700	21700
Antimony												R	
Arsenic	12	20 S	10	20 S	169 S	78 SN	86 SN	10 N	8.1 N	144 SN	19 N	20	153 SN
Barium	157	198	127	192	27	173	217	158	171	279	238	243	219
Beryllium	[0.85]	[0.86]	0.72	[0.89]	[0.84]	[0.86]	[1.0]	[0.67]	[0.86]	1.2	1.1	[0.94]	[1.0]
Cadmium	1.7	1.6	1.0	1.6	1.9	1.7	1.7	1.3	1.9	2.4	2.3	2.7	2.5
Calcium	18200	11400	16700	10600	22500	15100	10300	21100	15000	7930	24000	10700	11300
Chromium	22	17	13	19	28	25	26	18	26	25	25	23	28
Cobalt	14 E	16 E	11 E	16 E	14 E	[14]	15	12	15	34	14	14	18
Copper	41 E	37 E	27 E	37 E	42 E	36	37	32	38	46	52	52	45
Iron	30200	32500	22300	30900	29200	30100	33200	25800	31600	32900	35500	33800	47800
Lead	95 E	84 E	58 E	79 E	102 E	92	35	77	101	104	179	125	120
Magnesium	8780	6600	8400	5980	10200	8260	7070	7250	8940	5900	14000	7080	7810
Manganese	375	767	521	749	589	610 N	368 N	552 N	560 N	1290 N	472 N		540 N
Mercury	0.24 N	0.13 N	0.1 N	0.14 N	0.18 N	0.21	0.22	0.23	0.25	0.23	0.41	0.35	0.31
Nickel	39 E	40 E	29 E	41 E	40 E	38 E	41 E	33 E	41 E	94 E	43 E	43	45 E
Potassium	1620	1610	942	1450	1790	3460	2680	2120	2990	3270	3020	2040	3060
Selenium									[0.34] N				
Silver									0.47 N			R	
Sodium	[418]	[330]	[255]	[256]	[336]		[238]		[329]	[413]	[406]	NR	[301]
Thallium		[0.42]	[0.34]	[0.55]	[0.47]	0.49		[0.35]	[0.36]		[0.61]		
Vanadium	32	34	21	35	34	57	55	39	51	64	54	49	55
Zinc	212 E	206	179 E	256 E	397 E	154 E	165 E	132 E	185 E	265 E	540 E	540	219 E

Notes: Soil samples were collected in September 1986.

Blank spaces in table indicate that compound was analyzed for but not detected.

(EPA) U.S. EPA split sample result.

B Indicates that compound was found in blank samples.

J Indicates an estimated value; compound was found in sample at concentrations below the contract required detection limit.

[xx] See note for J above.

E Indicates that concentration is estimated due to presence of interference during analysis.

N Indicates that spike sample recovery is not within CLP control limits.

S Indicates that concentration was determined by method of standard additions.

R Indicates that data was rejected and considered unusable.

II Laboratory that analyzed Dames & Moore samples reportedly could not distinguish between these two isomers.

TABLE A-1 (Continued)
BOWERS LANDFILL
SOIL SAMPLES

Sample Location:	37	38	39	40	41	42	43	44	44(EPA)	45	46
ORGANIC COMPOUNDS (ug/kg)											
Volatiles											
Acetone	29 B	13 B	9.9 JB	31 B	11 JB	6.8 JB	56 B	9.4 JB	40 B	5.8 JB	24 B
Chloroform									4 JB		
Bromomethane											
Methylene Chloride	10 B	18 B	4.6 JB	8.8 B	12 B	12 B	38 B	16 B		2.7 JB	9.6 B
Toluene									5 B		
Semi-Volatiles											
Benzoic Acid					360 J			110 J			
Acenaphthene			280 J						34 J		
Fluoranthene	210 J	330 J	9100	220 J	83 J	360 J	400 J	660	1200 B	200 J	200 J
Naphthalene									18 J		
Bis(2-Ethylhexyl)Phthalate	150 J	62 J		200 J	150 J	380 J	270 J	370 J		110 J	44 J
Butyl Benzyl Phthalate								79 J	63 JB		
Di-N-Butyl Phthalate				130 J	180 J				51 J		
Di-N-Octyl Phthalate							80 J	130 J	280 JB		
Diethylphthalate									21 JB		
Benzo(a)anthracene	86 J	170 J	4300	100 J	41 J	210 J	160 J	290 J	530	120 J	140 J
Benzo(a)pyrene	130 J	170 J	4300	130 J	74 J	220 J	230 J	370 J	500	120 J	150 J
Benzo(b)fluoranthene-II	290 J	360 J	8600	290 J	54 J	470 J	510	960	530 B	250 J	280 J
Benzo(k)fluoranthene-II	290 J	360 J	8600	290 J	54 J	470	510	960	69 J	250 J	280 J
Chrysene	150 J	230 J	5200	160 J	66 J	230 J	240 J	410 J	690	160 J	160 J
Acenaphthylene			190 J						12 JB		
Anthracene			980 J					66 J	83 J		
Benzo(ghi)perylene	90 J	110 J	3100	82 J	70 J	180 J	170 J	300 J	680		120 J
Fluorene			710 J						41 J		
Phenanthrene	86 J	160 J	6800	78 J	50 J	190 J	170 J	420 J	600	98 J	100 J
Dibenzo(a,h)anthracene			960 J								
Indeno(1,2,3-cd)pyrene	65 J	98 J	2600	65 J	50 J	160 J	150 J	260 J	200 J		110 J
Pyrene	180 J	310 J	11000	180 J	91 J	350 J	320 J	560	920 B	220 J	250 J
Dibenzofuran			270 J						17 J		
2-Methylnaphthalene									11 J		
Pesticides and PCBs											
Beta-BHC											
Dieldrin											
Chlordane									210		
Arochlor-1242											
Arochlor-1248	350			700	1100						
Arochlor-1254						240					

TABLE A-1 (Continued)
BOWERS LANDFILL
SOIL SAMPLES

Sample Location:	37	38	39	40	41	42	43	44	44(EPA)	45	46
INORGANIC COMPOUNDS (mg/kg)											
Aluminum	18500	16000	9570	18200	25400	12800	11200	14400	12100	9600	10400
Antimony									R		
Arsenic	94 SN	19N	20N	103 SN	121 SN	13 N	15 N	102 SN	9.7	11	10
Barium	162	176	71	287	229	134	139	180	167	149	156
Beryllium	(0.88)	(0.80)	(0.70)	1.1	1.2	(0.68)	(0.66)	(0.73)	(0.78)	(0.76)	(0.69)
Cadmium	2.1	(0.85)		1.6	1.0	2.0	2.1	1.7	2.0	2.1	1.1
Calcium	13300	9580	96300	15800	10600	24800	25200	27100	24800	22000	15200
Chromium	24	20	9.9	22	28	25	21	27	24	22	17
Cobalt	16	15	7.9	15	16	(11)	12	12	(12)	(12) E	13 E
Copper	42	37	22	55	35	33	37	39	37	34 E	33 E
Iron	36500	31900	17500	35400	38400	22400	24400	26600	24200	23100	25300
Lead	106	85	80	147	100	85	92	155	147	74 E	67 E
Magnesium	7680	6260	22900	7440	6720	10700	11300	11800	11400	8340	5840
Manganese	531 N	486 N	374 N	745 N	568 N	436 N	519 N	567 N		552	716
Mercury	0.36	0.29	0.15	0.43	0.14	0.4	0.58	0.32	0.41	0.31 N	0.32 N
Nickel	40 E	40 E	20 E	40 E	39 E	30 E	30 E	33 E	30	34 E	34 E
Potassium	2330	2330	1780	2710	4190	2230	1550	2090	1310	(1090)	1300
Selenium						(0.56) N					
Silver									R		
Sodium		(275)	(770)	(267)	(282)	(418)	(290)	(374)		(413)	(277)
Thallium											(0.49)
Vanadium	43	42	25	52	71	35	28	35	31	22	23
Zinc	245 E	149 E	87 E	234 E	159 E	153 E	189 E	211 E	195	220 E	210 E

Notes: Soil samples were collected in September 1986.

Blank spaces in table indicate that compound was analyzed for but not detected.

(EPA) U.S. EPA split sample result.

B Indicates that compound was found in blank samples.

J Indicates an estimated value; compound was found in sample at concentrations below the contract required detection limit.

(xx) See note for J above.

E Indicates that concentration is estimated due to presence of interference during analysis.

N Indicates that spike sample recovery is not within CLP control limits.

S Indicates that concentration was determined by method of standard additions.

R Indicates that data was rejected and considered unusable.

II Laboratory that analyzed Dames & Moore samples reportedly could not distinguish between these two isomers.

TABLE A-2
 BOWERS LANDFILL
 GROUND-WATER SAMPLES (ROUNDS 1, 2, AND 3)

Sample Location:	W-4(1)	W-4(2)	P-4A(1)	P-4A(2)	W-5(1)	W-5(2)	W-5 (2-DUP)	P-5A(1)	P-5A (1-DUP)	P-5A(2)	P-5B(1)	P-5B(2)	P-5B(3)
ORGANIC COMPOUNDS (ug/L)													
Volatiles													
Benzene													
Methylene Chloride		3.0 J					2.4 J		1.2 J				
Acetone											5.0 J		
Tetrachloroethene													
Semi-Volatiles													
Bis(2-Ethylhexyl)Phthalate		4.4 J						2.5 J			11 J		3 J
Di-N-Butyl Phthalate													
2-Methylnaphthalene													
N-Nitrosodiphenylamine													
INORGANIC COMPOUNDS (ug/L)													
Aluminum	[30]						[53]				[24]		
Arsenic	[3.6]	[8.4] N	[7.8]	[6.7] N	[3.0] N	[6.8] N		[2.5] N	[1.8]	[4.4] N	[8.7] N	11 N	[8.1]
Barium	[154] E	[149]	[154] E	[143]	217	213	204	202	203 E	[195]	2020	2020	2070
Calcium	113000	103000	107000	100000	80300	82600	79300	80500	83400	79200	71600	67300	69100
Chromium													
Cobalt											[3.9]		
Copper	[11]	[2.3]	[4.4]	[1.2]					[18]				
Iron	[55]	[67]	1250	376	1100	796	728	[95]	149	[7.4]	615	[87]	383
Lead													
Cyanide	20												
Magnesium	38100	35100	36700	34800	25600	26300	25200	26000	26800	25400	36900	35600	36700
Manganese	395 E	239 E	53 E	42 E	92 E	68 E	67 E	203 E	205 E	132 E	159 E	134 E	499 E
Mercury		0.76 N		0.22 N									
Nickel													
Potassium											7060	5120	7410
Selenium						[2.6]							[17] N
Sodium	7700 E	7190	14600 E	13700	11100 E	5920	5640	11600 E	17200 E	7280	183000 E	173000	171000
Vanadium													
Zinc	[18]	[9.7]	24	[9.3]	[14] E	[5.0]	[8.0]	[12] E	[13]	[6.4]	[11] E	[8.0]	[17]

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TABLE A-2 (Continued)
BOWERS LANDFILL
GROUND-WATER SAMPLES (ROUNDS 1, 2, AND 3)

Sample Location:	V-6(1)	V-6 (1-DUP)	V-6 (1-EPA)	V-6(2)	P-6A(1)	P-6A(2)	P-6B(1)	P-6B (1-EPA)	P-6B(2)	P-6B (2-DUP)	P-6B(3)	V-7(1)	V-7(2)
ORGANIC COMPOUNDS (ug/L)													
Volatiles													
Benzene							2.2 J	6			4 J		
Methylene Chloride													3.6 J
Acetone	8.8 J						11 B	64	14	12			
Tetrachloroethene													
Semi-Volatiles													
Bis(2-Ethylhexyl)Phthalate						2.0 J					3 J	13 J	
Di-N-Butyl Phthalate												2.6 J	
2-Methylnaphthalene							2.8 J						
N-Nitrosodiphenylamine													
INORGANIC COMPOUNDS (ug/L)													
Aluminum			[163]					[44]					
Arsenic	[3.6]	[4.1]			[4.1]								
Barium	226 E	223 E	224	234	[114] E	[4.1] M	[4.4]		[3.7]				20 M
Calcium	107000	106000	113000	107000	89200	[120]	488 E	489	531	522	548	335 E	383
Chromium			18				58600	63400	59000	57800	58600	97900	93500
Cobalt	[2.2]	[2.2]						11					
Copper	[17]	[17]	[18.2]		[17]		[15]	[6.5]				[4.2]	
Iron	367	272	409	[47]	154		107	197	273 E	263 E	516	864	3700
Lead									8.5 S+N	10 M			
Cyanide													
Magnesium	38000	38000	39900	38200	34500	33600	23500	25400	24400	23800	23300	33500	39900
Manganese	1350 E	1360 E	1500	1330 E	332 E	333 E	192 E	220	183 E	178 E	193 E	347 E	126 E
Mercury													
Nickel													
Potassium			[696]					5000					
Selenium													
Sodium	21000 E	19600 E	18400	10300	7880 E	[3120]	29700 E	30500	20600	20300	18100	10000 E	7490
Vanadium												[5.6]	
Zinc	[16]	[11]	[11]	[9.4]	[14]	[3.3]	[10]	[6.2]	[7.5]	[9.0]	[5.2]	21	[9.0]

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TABLE A-2 (Continued)
BOUERS LANDFILL
GROUND-WATER SAMPLES (ROUNDS 1, 2, AND 3)

Sample Location:	P-7A(1)	P-7A(2)	P-7A (2-EPA)	W-8(1)	W-8(2)	P-8A(1)	P-8A(2)	P-8B(1)	P-8B(2)	P-8B(3)	W-9(1)	W-9(2)	W-10(1)
ORGANIC COMPOUNDS (ug/L)													
Volatiles													
Benzene													
Methylene Chloride			6 B										
Acetone													6.9 JB
Tetrachloroethene													
Semi-Volatiles													
Bis(2-Ethylhexyl)Phthalate	21			10 J						7 J	3.6 J		6.8 J
Di-N-Butyl Phthalate													
2-Methylnaphthalene													
N-Nitrosodiphenylamine													
INORGANIC COMPOUNDS (ug/L)													
Aluminum											(27)		
Arsenic	(11)			(4.8)	(4.3)	(3.7)	(6.0)	(2.0)		(2.0)			(2.0)
Barium	309 E	306	306	287 E	308	322 E	308	596 E	684	691	(102) E	(101)	(122) E
Calcium	92700	101000	97600	93900	98000	99800 +	98800	95900	95400	97400	119000	101000	133000
Chromium													
Cobalt	(3.6)												(3.1)
Copper	(18)			(17)		(3.3)		(6.6)			(13)		(18)
Iron	1100	(58) E	618	498	521 E	846	1380 E	994	948 W	630	(12)	(20) E	165
Lead			6.9		(3.0) N		(3.5) N		(4.4) N			(3.7) N	
Cyanide													
Magnesium	39300	35800	33400	31800	34000	34500	34600	36000	36900	35700	33400	28800	50600
Manganese	314 E	324 E	395 E	141 E	121 E	198 E	177 E	230 E	234 E	233 E	26 E	19 E	1890 E
Mercury			<0.2										
Nickel		(28)											
Potassium		5270	(1100)										
Selenium													
Sodium	12900 E	9420	6290	6300 E	(1960)	5160 E	(2330)	17900 E	15400	16600	6550 E		23900 E
Vanadium	(4.0)	(3.9)								(3.2)			
Zinc	(13)	(11)		22	(16)	(17)	(13)	(11)	(13)	(12)	(13)	(12)	22

TABLE A-2 (Continued)
BOWERS LANDFILL
GROUND-WATER SAMPLES (ROUNDS 1, 2, AND 3)

Sample Location:	W-10 (1-DUP)	W-10(2)	W-11(1)	W-11(2)	W-12(1)	W-12(2)	W-12 (2-DUP)	W-12 (2-EPA)	P-12B(3)	P-12B (3-DUP)	W-13(1)	W-13(2)	P-13B (2-DUP)
ORGANIC COMPOUNDS (ug/L)													
Volatiles													
Benzene													
Methylene Chloride						5.1	7.4	4 BJ					
Acetone						14							
Tetrachloroethene					4.4 J	5.3	5.3						
Semi-Volatiles													
Bis(2-Ethylhexyl)Phthalate	5.2 J		6.2 J		4.0 J				9 J	10 J			
Di-N-Butyl Phthalate													
2-Methylnaphthalene													
N-Nitrosodiphenylamine											4.3 J		
INORGANIC COMPOUNDS (ug/L)													
Aluminum			[26]		[33]								
Arsenic	[2.2]		[8.6]	[5.6]							[6.7]	17 M	11 M
Barium	[119] E	[110]	348 E	351	[198] E	[184]	[180]	[180]	[177]	[194]	264 E	300	305
Calcium	132000	129000	117000	130000	123000	117000	113000	108000	75900	80800	76000	77300	78000
Chromium													
Cobalt	[1.7]		[1.2]										
Copper	[18]		[15]		[15]			[7.4]			[3.9]		
Iron	294	[30] E	8760	5930 E	[4.1]	106		[66]	[76]	[46]	7110	6000	5980
Lead		[4.9] M		9.2 M				7.0					
Cyanide													
Magnesium	50400	49800	35100	36600	35100	33800	32700	33000	27700	29300	22600	23700	23800
Manganese	1880 E	657 E	264 E	347 E	[7.5] E	[2.4] E	[2.0] E	[1.6] E	753 E	795 E	300 E	305 E	309 E
Mercury													
Nickel													
Potassium								[2670]	6550	[2800]			
Selenium								26 M					
Sodium	22900 E	20300	17200 E	15000	5300 E	[3380]		5300	11800	9810	8410 E	6460	7920
Vanadium									[10]				
Zinc	[19]	20	[14]	[19]	21	[6.7]	[3.7]		[9.7]	[5.6]	[16]	[6.1]	[5.8]

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TABLE A-2 (Continued)
 BOWERS LANDFILL
 GROUND-WATER SAMPLES (ROUNDS 1, 2, AND 3)

Sample Location: P-13B(3) RV-14(1) RV-15(1) RV-16(1) RV-16 (1-DUP) RV-17(1)

ORGANIC COMPOUNDS (ug/L)

Volatiles

Benzene					
Methylene Chloride	1 J	4.3 J		2.4 J	
Acetone					
Tetrachloroethene					

Semi-Volatiles

Bis(2-Ethylhexyl)Phthalate	5 J
Di-N-Butyl Phthalate	
2-Methylnaphthalene	
N-Nitrosodiphenylamine	

INORGANIC COMPOUNDS (ug/L)

Aluminum					(36)
Arsenic		16	14	11	11
Barium	368	(125)	(130)	(93)	(93)
Calcium	78500	97100	101000	89700	88400
Chromium					
Cobalt					
Copper					32
Iron		2510	30000	2370	2250
Lead					4670
Cyanide					
Magnesium	27900	33500	34200	31300	30900
Manganese	50 E	39 E	51 E	42 E	42 E
Mercury					
Nickel					
Potassium					
Selenium					
Sodium	6840	8360 E	19800 E	10400 E	9980 E
Vanadium					9710 E
Zinc	(4.9)	(16) E	20 E	20 E	22 E
					174 E

10:30-1 3-5

TABLE A-2 (Continued)
BOWERS LANDFILL
GROUND-WATER SAMPLES (ROUNDS 1, 2, AND 3)

Notes: Blank spaces in table indicate that compound was analyzed for but not detected.

(1) Round 1 samples collected in February 1987.

(2) Round 2 samples collected in April 1987.

(3) Round 3 samples collected in March 1988.

(DUP) Dames & Moore field duplicate sample result.

(EPA) U.S. EPA split sample result.

B Indicates that compound was found in blank samples.

J Indicates an estimated value; compound was found in sample at concentrations below the contract required detection limit.

[xx] See note for J above.

E Indicates that concentration is estimated due to presence of interference during analysis.

N Indicates that spike sample recovery is not within CLP control limits.

S+ Indicates that concentration was determined by method of standard additions but correlation coefficient was less than 0.995.

TABLE A-3
BOWERS LANDFILL
SURFACE WATER SAMPLES (ROUND 1 AND 2)

Sample Location:	18(1)	18(2)	19(1)	19(2)	20(1)	20(2)	21(1)	21 (1-DUP)	21 (2)	21 (2-DUP)	22(1)	22 (1-EPA)	22(2)
ORGANIC COMPOUNDS (ug/L)													
Volatiles													
1,2-Dichloroethane											2.7 J	3 J	
Methylene Chloride	2.8 J		3.2 JB		3.5 J					1.3 JB	5.2		2.1 JB
Acetone													
Tetrachloroethene	1.1 J				1.1 J						1.0 J		
Semi-Volatiles													
Bis(2-Ethylhexyl)Phthalate		2.2 JB		2.4 JB					2.2 JB				5.4 JB
Diethylphthalate											3.0 J		
Pesticides and PCBs													
Aroclor-1260	1.2							2.6					
INORGANIC COMPOUNDS (ug/L)													
Aluminum	[123]	[156]	[154]	[150]	[108]	[152] *	[62]	[29]	[111]	[102]	120	256	[158]
Arsenic									[4.3]	[4.6]			
Barium	[52]	[60]	[48]	[59]	[50]	[59]	[78]	[79]	[99]	[102]	[49]	[53]	[59]
Calcium	75400	76800	73300	75800	77100	75300	74900	75000	64900	66300	76900	85700	76400
Chromium												11	
Cobalt													
Copper												[6.8]	
Iron	294	406 E	358	438 E	234	413 E	811	640	2540 E	2450 E	243	471	383 E
Lead		6.6 N		[4.8] S+N		8.0 N			[2.9] N	9.4 N			77 N
Cyanide		ND		10		12						13	10
Magnesium	25400	26300	24600	25800	25900	25700	22600	22600	21100	21700	25700	28500	26100
Manganese	34 E	55 E	34 E	55 E	34 E	55 E	115 E	111 E	189 E	195 E	37 E	37	56 E
Mercury											0.23 N	0.2	
Potassium												[4470]	
Selenium													
Silver													
Sodium	37800 E	26600	37500 E	26100	36400 E	27000	9240 E	8650 E	[4830]	[4190]	39400 E	42100	29000
Thallium													
Vanadium													
Zinc	34 E	27	25 E	33	27 E	30	[18] E	[14] E	23	[9.9]	29 E	22	28

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TABLE A-3 (Continued)
BOWERS LANDFILL
SURFACE WATER SAMPLES (ROUND 1 AND 2)

Sample Location:	23(1)	23(2)	24(1)	24(2)	25(1)	25(2)	26(1)	26(2)	27(1)	27(2)	28(1)	28 (1-DUP)	28(2)
ORGANIC COMPOUNDS (ug/L)													
Volatiles													
1,2-Dichloroethane	3.1 J												
Methylene Chloride	5.7			1.6 J			1.4 JB						
Acetone	5.1 JB												
Tetrachloroethene													
Semi-Volatiles													
Bis(2-Ethylhexyl)Phthalate													
Diethylphthalate													
Pesticides and PCBs													
Aroclor-1260													
INORGANIC COMPOUNDS (ug/L)													
Aluminum	117	[163]	[89]	[106]	810	263	[78]	[138]	[39]	213	[62]	[32]	
Arsenic				[7.1] M			[2.9] M	[4.4]		[4.0] M			
Barium	50	[60]	[80]	[77]	[112]	[93]	[79]	[101]	[91]	[100]	[112]	[113]	[145]
Calcium	76600	75500	76600	58500	71300	46700	74800	65300	77000	70000	121000	118000	121000
Chromium													
Cobalt											[3.8]	[2.9]	
Copper								[5.3]		[4.9]			
Iron	252	450 E	465	517	2060	636 E	289	426 E	127	944	980	1040	214 E
Lead		[4.3] M											[4.4] M
Cyanide		16											
Magnesium	25700	25900	23200	19000	25900	23200	23400	20800	27200	24300	47400	46300	45700
Manganese	35 E	55 E	154 E	83 E	98	28 E	143 E	110	33 E	122 E	787 E	817	28 E
Mercury								0.27					
Potassium								[4440]					
Selenium													
Silver								21 M				[4.0]	
Sodium	39700 E	27300 E	10700 E	[4590]	13500	[4980]	10900 E	9620	5310 E	[2860]	19700 E	18800	9910
Thallium											[2.6] M		
Vanadium								[3.8]			[4.2]		
Zinc	33 E	37	18 E	[10]	[14]	[17]	11 E	25 E	[18] E	[13]	48 E	43	[17]

TABLE A-3 (Continued)
BOWERS LANDFILL
SURFACE WATER SAMPLES (ROUND 1 AND 2)

Sample Location:	29(1)	29(2)	29 (2-DUP)	29 (2-EPA)
ORGANIC COMPOUNDS (ug/L)				
Volatiles				
1,2-Dichloroethane				
Methylene Chloride				15 B
Acetone				
Tetrachloroethene				
Semi-Volatiles				
Bis(2-Ethylhexyl)Phthalate				
Diethylphthalate				
Pesticides and PCBs				
Aroclor-1260				
INORGANIC COMPOUNDS (ug/L)				
Aluminum	[43]	1140	1080	1580 E
Arsenic		[7.4] M	[7.3] M	
Barium	[82]	[118]	[119]	[199]
Calcium	73000	74500	73800	77100
Chromium				[7.1]
Cobalt				
Copper		[5.8]	[5.0]	[9.2]
Iron	362	2420	2460	2790
Lead				8.6 S
Cyanide				
Magnesium	26600	27100	26800	27900
Manganese	41	162 E	163 E	171 E
Mercury				
Potassium				[2360]
Selenium				
Silver				
Sodium	[2850]	[3830]	[2730]	5860
Thallium				
Vanadium				
Zinc	[7.6]	[19]	[17]	87

TABLE A-3 (Continued)
BOWERS LANDFILL
SURFACE WATER SAMPLES (ROUND 1 AND 2)

Notes: Blank spaces in table indicate that compound was analyzed for but not detected

(1) Round 1 samples collected in February 1987.

(2) Round 2 samples collected in April 1987.

(DUP) Dames & Moore field duplicate sample result.

(EPA) U.S. EPA split sample result.

B Indicates that compound was found in blank samples.

J Indicates an estimated value; compound was found in sample at concentrations below the contract required detection limit.

[xx] See note for J above.

E Indicates that concentration is estimated due to presence of interference during analysis.

N Indicates that spike sample recovery is not within CLP control limits.

S Indicates that concentration was determined by method of standard additions.

S+ Indicates that concentration was determined by method of standard additions but correlation coefficient was less than 0.995.

TABLE A-4
BOWERS LANDFILL
SEDIMENT SAMPLES (ROUNDS 1 AND 2)

Sample Locations:		18(1)	18(2)	19(1)	19(2)	20(1)	20(2)	21(1)	21 (1-DUP)	21(2)	21 (2-DUP)	22(1)	22 (1-EPA)	22(2)
ORGANIC COMPOUNDS (ug/kg)														
Volatiles														
Chloroform			5.6 J											
Methylene Chloride		22 B	30 B	14 B	19 B	19 B	24 B	31 B	15 B	50 B	53 B	13 B	43	54 B
Toluene														(61)
Acetone		19 B	27 B	16 B	20 B	15 JB	15 B	8.3 JB	14 JB	27 B	32 B	36 B	70	148 B
Semi-Volatiles														
Phenol										440 J	540 J			
Benzoic Acid										810 J	1100 J			340 J
4-Methylphenol										8100	6800			8600
Fluoranthene		700	900	440 J	430 J	440 J	370 J	200 J	220 J	670 J	690 J	440 J	1000	540 J
Bis(2-Ethylhexyl)Phthalate		520 B	660 B	840	950 B	1100	900 B	170 J	240 J	1600 B	1500 B	540 J	840	2000 B
Butyl Benzyl Phthalate							72 J							
Di-N-Butyl Phthalate							120 J							
Di-N-Octyl Phthalate		120 J	72 J	88 J	70 J	160 J	110 J			180 J				190 J
Benzo(a)anthracene		410 J	420 J	3600	270 J	180 J	190 J	120 J	120 J	340 J	400 J	230 J	370 J	330 J
Benzo(a)pyrene		450 J	370 J	330 J	240 J	290 J	190 J	120 J	120 J	350 J	320 J	190 J	370 J	290 J
Benzo(b)fluoranthene-II		910	890	750	550	560	400 J	250 J	250 J	880 J	760 J	380 J	480 J	730
Benzo(k)fluoranthene-II		910	890	750	550	560	400 J	250 J	250 J	880 J	760 J	380 J	370 J	730
Chrysene		550	490 J	370 J	330 J	340 J	260 J	140 J	160 J	500 J	490 J	250 J	480	390 J
Acenaphthylene														
Anthracene		120 J	110 J	76 J									100 J	72 J
Benzo(ghi)perylene		320 J	280 J	260 J		120 J		89 J	77 J	210 J	260 J	64 J		170 J
Fluorene		60 J												
Phenanthrene		490 J	600 J	300 J	280 J	550 J	220 J	110 J	100 J	470 J	600 J	220 J	420 J	210 J
Dibenzo(a,h)anthracene		160 J	84 J	130 J										
Indeno(1,2,3-cd)pyrene		290 J	260 J	250 J		120 J	120 J	74 J	72 J	210 J	250 J	82 J		160 J
Pyrene		700	810	460 J	410 J	590	340 J	200 J	200 J	620 J	640 J	380 J	610	510 J
Pesticides and PCBs														
Chlordane						200		120	140			170		
Arochlor-1248														

A-15

TABLE A-5 (Continued)

Parameter	Burgess & Niple Sampling Locations (1)								
	MW-1 7/17/81	MW-1 8/20/81	MW-1 9/15/81	MW-2 7/17/81	MW-2 8/20/81	MW-2 9/15/81	MW-3 7/17/81	MW-3 8/20/81	MW-3 9/15/81
Nickel	0.03	0.007	NA	0.15	ND	NA	NA	ND	NA
Selenium	ND	NA	NA	ND	NA	NA	NA	NA	NA
Silver	ND	NA	NA	ND	NA	NA	NA	NA	NA
Thallium	0.019	ND	NA	0.009	ND	NA	NA	ND	NA
Zinc	0.1	NA	NA	0.05	NA	NA	NA	NA	NA
3. Organic Parameters									
Benzene(2)	ND	NA	NA	0.03	NA	NA	NA	NA	NA
Diethyl phthalate (2)	ND	NA	NA	0.01	NA	NA	NA	NA	NA
Ethylbenzene(2)	ND	NA	NA	2.48	NA	NA	NA	NA	NA
Ethylbenzene(3)	ND	ND	ND	66.8	40.0	76.0	NA	10.0	11.0
Methylene chloride(2)	ND(B)	NA	NA	0.10(B)	NA	NA	NA	NA	NA
Mixed xylenes(2)	ND	ND	ND	27	86.0	74.0	NA	34.0	20.0
Naphthalene(2)	ND	NA	NA	0.19	NA	NA	NA	NA	NA
Phenols(2)	ND	NA	NA	0.06	NA	NA	NA	NA	NA
Phenols(4)	0.016	0.07	0.06	1.0	0.96	1.12	0.0021	0.37	0.08
Toluene(2)	ND	NA	NA	2.53	NA	NA	NA	NA	NA
Toluene(3)	ND	ND	ND	43.4	53.0	62.0	NA	18.0	11.0
Trichloroethylene(2)	ND	NA	NA	0.02	NA	NA	NA	NA	NA
1,2,-Trans-dichloroethylene(2)	ND	NA	NA	0.09	NA	NA	NA	NA	NA
2,4-Dimethylphenol(2)	NC	NA	NA	0.04	NA	NA	NA	NA	NA

NA = parameter not analyzed for.

ND = parameter analyzed for but not detected.

B - parameter detected in laboratory blank.

(1) Sampling locations on Drawing 1-3.

(2) Gas chromatography/mass spectrometry.

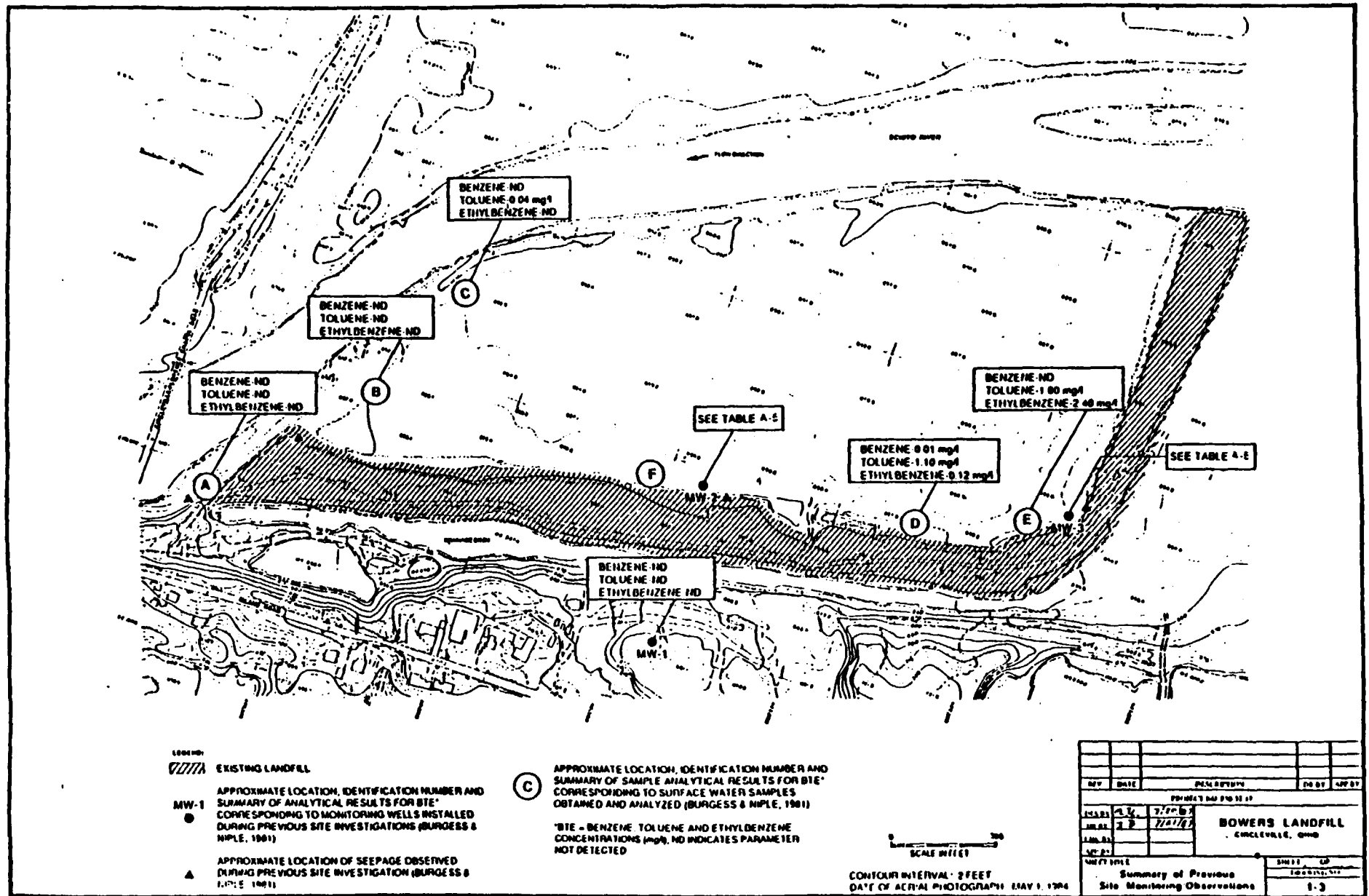
(3) Gas chromatography - liquid extraction.

(4) Spectrophotometry.

Source: Dames & Moore, 1987a

FIGURE A-1 LOCATIONS OF SAMPLES COLLECTED BY U.S. EPA AND BURGESS & NIPLE

A-25



Source: Dames & Moore, 1987a

TABLE A-6

SUMMARY OF PREVIOUSLY REPORTED SAMPLING AND ANALYSIS DATA
BOWERS LANDFILL - CIRCLEVILLE, OHIO

PARAMETER	Date:	May 3, 1982							May 18, 1983			
		Location:	Point F	Point G	Point H	Point I	Point J	Point K	Pipe Discharge	West 1	West 2	West 3
1. Inorganic Parameters (mg/L)												
Arsenic		0.012	0.027	ND	1.60	ND	0.60	ND	0.011	0.012	0.015	0.025
Barium		0.40	1.20	0.80	11.0	0.40	11.00	0.30	0.20	0.20	0.20	0.30
Cadmium		ND	ND	ND	0.15	ND	ND	ND	ND	ND	ND	ND
Chromium		ND	ND	ND	1.40	ND	1.50	ND	ND	ND	ND	ND
Copper		ND	0.04	0.11	2.40	ND	2.20	ND	NA	NA	NA	NA
Lead		ND	0.02	0.21	2.90	ND	ND	ND	ND	ND	ND	0.006
Magnesium		70	70	63	480	30	480	24	NA	NA	NA	NA
Manganese		6.85	8.60	3.80	83.0	1.04	26.5	0.40	NA	NA	NA	NA
Mercury		ND	ND	0.0024	0.0035	ND	0.0063	ND	ND	ND	ND	ND
Selenium		0.008	0.012	0.006	ND	0.008	0.010	0.007	ND	ND	ND	ND
Silver		ND	ND	ND	2.30	ND	ND	ND	ND	ND	ND	ND
Zinc		ND	0.70	2.00	13.80	ND	13.2	ND	NA	NA	NA	NA
2. Organic Parameters (mg/L)												
Dibutoxymethanol		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene		ND	ND	ND	4.2	ND	13.0	ND	4.0	ND	1.1	0.6
Methyl isobutyl ketone		ND	ND	ND	1.8	ND	ND	ND	ND	ND	ND	ND
Phenol		0.060	0.008	0.007	1.12	0.003	0.332	0.006	NA	NA	NA	NA
Toluene		ND	ND	ND	47.7	ND	ND	ND	5.0	ND	7.1	1.2
Xylenes		ND	ND	ND	12.1	ND	2.9	ND	4.6	ND	2.5	0.7

NA = Parameter not analyzed for

ND = Parameter analyzed for but not detected

NQ = Parameter detected but not quantified because not in standard

Source: Laboratory Reports from Industrial Chemistry Section, Ohio Department of Health, 1982 and 1983

TABLE A-6

SUMMARY OF PREVIOUSLY REPORTED SAMPLING AND ANALYSIS DATA
BOWERS LANDFILL - CIRCLEVILLE, OHIO

PARAMETER	Date:	May 3, 1982							May 18, 1983			
	Location:	Point F	Point G	Point H	Point I	Point J	Point K	Pipe Discharge	West 1	West 2	West 3	North 1
1. Inorganic Parameters (mg/L)												
Arsenic		0.012	0.027	ND	1.60	ND	0.60	ND	0.011	0.012	0.015	0.025
Barium		0.40	1.20	0.80	11.0	0.40	11.00	0.30	0.20	0.20	0.20	0.30
Cadmium		ND	ND	ND	0.15	ND	ND	ND	ND	ND	ND	ND
Chromium		ND	ND	ND	1.40	ND	1.50	ND	ND	ND	ND	ND
Copper		ND	0.04	0.11	2.40	ND	2.20	ND	NA	NA	NA	NA
Lead		ND	0.02	0.21	2.90	ND	ND	ND	ND	ND	ND	0.006
Magnesium		70	70	63	480	30	480	24	NA	NA	NA	NA
Manganese		6.85	8.60	3.80	83.0	1.04	26.5	0.40	NA	NA	NA	NA
Mercury		ND	ND	0.0024	0.0035	ND	0.0063	ND	ND	ND	ND	ND
Selenium		0.008	0.012	0.006	ND	0.008	0.010	0.007	ND	ND	ND	ND
Silver		ND	ND	ND	2.30	ND	ND	ND	ND	ND	ND	ND
Zinc		ND	0.70	2.00	13.80	ND	13.2	ND	NA	NA	NA	NA
2. Organic Parameters (mg/L)												
Dibutoxymethanol		ND	ND	ND	NQ	ND	ND	ND	NQ	ND	ND	ND
Ethylbenzene		ND	ND	ND	4.2	ND	13.0	ND	4.0	ND	1.1	0.6
Methyl isobutyl ketone		ND	ND	ND	1.8	ND	ND	ND	ND	ND	ND	ND
Phenol		0.060	0.008	0.007	1.12	0.003	0.332	0.006	NA	NA	NA	NA
Toluene		ND	ND	ND	47.7	ND	ND	ND	5.0	ND	7.1	1.2
Xylenes		ND	ND	ND	12.1	ND	2.9	ND	4.6	ND	2.5	0.7

NA = Parameter not analyzed for

ND = Parameter analyzed for but not detected

NQ = Parameter detected but not quantified because not in standard

Source: Laboratory Reports from Industrial Chemistry Section, Ohio Department of Health, 1982 and 1983

FIGURE A-2 LOCATIONS OF SAMPLES COLLECTED BY OHIO EPA

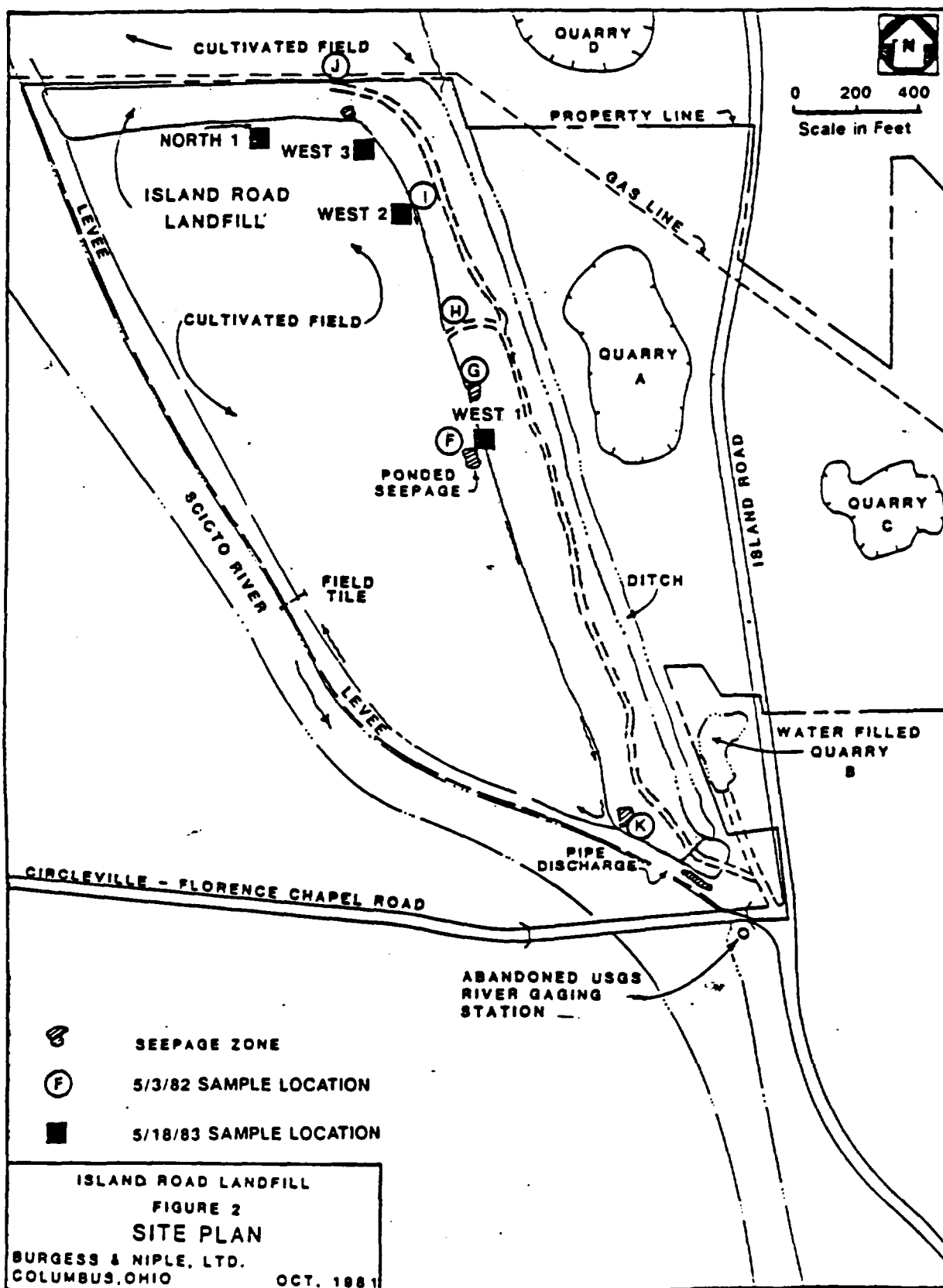


TABLE A-7
SUPPLEMENTAL SOIL SAMPLE RESULTS
(Soil Samples Collected in March 1988)

<u>Location</u>	<u>Sample No.</u>	<u>Arsenic (mg/kg)</u>	<u>Lead (mg/kg)</u>
Agricultural Areas	SO11	8.4	44
	SO11 DUP	8.5	41
	SO49	7.6	25
	SO50	ND	23
Landfill	SO34	7.8	26
	SO36	7.9	26
	SO47	8.1	39
	SO47 DUP 1	8.4	50
	SO47 DUP 2	6.3	131
	SO48	11	18
West of Scioto River (background)	SO51	8.6	41
	SO52	5.4	40
	SO53	7.5	28

Notes:

ND - Indicates element was analyzed for but not detected.

All sampling locations are shown on Figure 1-6 of the report.

APPENDIX B

**DEFINITIONS OF FATE
AND TRANSPORT PROCESSES**

APPENDIX B

DEFINITION OF FATE AND TRANSPORT PROCESSES

The purpose of this appendix is to define the processes that affect the fate and transport of the substances described in Chapter 2. For clarity, the processes mentioned in Chapter 2 may be classified as physical (transport), chemical, and biological as indicated below:

1. Transport Processes

- o Volatilization
- o Sorption
- o Advection

2. Chemical Processes

- o Photolysis
- o Oxidation
- o Hydrolysis

3. Biological Processes

- o Bioaccumulation
- o Biotransformation/Biodegradation

This appendix also discusses and defines the octanol/water partition coefficient. This coefficient is very important in dealing with fate and transport because it can be used in correlations to predict the properties of substances such as water solubility, soil/sediment adsorption coefficients, and bioconcentration factors.

TRANSPORT PROCESSES

Volatilization

Volatilization can be an important pathway for the transport of chemicals from water and soil into the atmosphere. The volatilization rate, is used to estimate concentration changes in water and soil and the amount of a

chemical introduced into the atmosphere. Volatilization rate is usually affected by the properties of both the chemical substance and the medium. In the aqueous environment, water depth and flowrate affect the water's (mixing) and are thus important physical considerations. Chemical properties of the substance that influence the volatilization rate include vapor pressure, solubility, and molecular weight. The higher the vapor pressure, the higher the tendency of the substance to escape from the water medium into the atmosphere. Similarly, the lower the solubility, the higher the substance's tendency to leave the water phase. In general, the lower the molecular weight, the faster the specie moves. Conditions at the air-water interface are equally significant, since they affect resistance to mass-transfer. Wind velocity and temperature are parameters that affect the mass-transfer rate, as well as the distribution of the compound introduced into the atmosphere. Mathematically, the rate of volatilization is generally assumed to be a first order process as given in the following equation:

$$R_v = K_v C_w$$

where R_v = volatilization rate of a substance (moles/liter-hr)

K_v = volatilization rate constant (hr^{-1})

C_w = concentration of the substance in water (mole/liter)

The volatilization rate constant may be determined by following concentration decay versus time of the substance in the control volume and subjecting the resulting data to first order rate analysis.

Sorption

Sorption of a substance onto suspended sediments, bottom sediment, or soil particles is an important environmental process. "Sorption" is used to describe transport processes that include both adsorption and absorption since these terms are not always easily distinguishable. Adsorption is the movement of a substance from one phase onto the surface of another phase, while absorption involves movement into and uniform distribution within the new phase. Data on sorption is usually reported with the aid of equilibrium models such as the Freundlich model given below:

$$q_e = K C_w^{1/n}$$

where q_e = concentration of substance in particulate/sediment (mg/g)

C_w = concentration of substance in water (mg/l)

K = equilibrium constant (l/g)

n = equilibrium constant

The above equation relates a substance's concentration on the sediment to that in the liquid at equilibrium and at constant temperature. The equilibrium constants K and n indicate the sorption capacity and intensity, respectively. At concentrations found in the environment (generally low concentration), the equilibrium constant n is approximately unity, hence the above expression reduces to the Henry's law type of equation, or $q_e = KC_w$.

Advection

Advection refers to the bulk movement of ground water. This transport mechanism is the main factor in the distribution of contaminants in saturated aquifers. The dissolved contaminants in ground water disperse as they move with the bulk flow. The extent of dispersion is generally controlled by the mixing and molecular diffusion coefficients of the contaminants.

CHEMICAL PROCESSES

Photolysis refers to the transformation or degradation of a substance after absorption of light energy. This reaction may occur in aquatic media or in the atmosphere. Two types of photolysis are generally recognized: direct photolysis and sensitized photolysis. Direct photolysis refers to photodegradation or transformation of a substance resulting from direct absorption of light energy by the substance. Sensitized photolysis refers to photodegradation or transformation of a substance in which energy is indirectly transferred to the target substance from some other species in the aquatic medium. The rate of photolysis depends on the properties of both the substance and the medium. Photolysis of chemicals in aquatic and soil media and in the lower troposphere occurs at light wavelengths greater than 290 nm, since ozone in the stratosphere filters out light of shorter wavelengths. Photochemical processes are generally expressed with first or second rate equations, depending on the mechanism.

$$R_p = K_p(C) \quad \text{for direct photolysis}$$

$$R_p^* = K_2(C)(X) \quad \text{for sensitized photolysis}$$

where R_p - direct photolytic rate of the substance (moles/liter-hr)
 R_p^* - sensitized photolytic rate of the substance (moles/liter²-hr)
 K_p - photolytic rate constant (hr⁻¹)
 C - concentration of the substance in the medium (mole/liter)
 K_2 - second order photolytic rate constant (mole⁻¹hr⁻¹)
 X - concentration of reactive intermediate (mole/liter)

Oxidation

Oxidation refers to the degradation or transformation of a substance by oxidants. This may be as a result of the action of singlet oxygen atom or

of other free radicals present in the medium. The mathematical expression generally used to express this type of reaction is shown below:

$$R_o = K(OX)(C)$$

where R_o = rate of oxidation (moles/liter²-hr)

K = second order rate constant (moles⁻¹hr⁻¹)

OX = concentration of the oxidant (moles/liter)

C = concentration of the substance (moles/liter)

Hydrolysis

Hydrolysis refers to a chemical transformation process in which a molecule (MX) reacts with water, forming a new compound (new carbon-oxygen bond) with the loss of a leaving group (X). The chemical reaction may be represented as:



The rate of hydrolysis depends on the hydronium ion concentration. First order rate expressions can be used to model the chemical process as shown below:

$$R_H = K_H (C)$$

where R_H = rate of hydrolysis (moles/liter-hr)

K_H = first order rate constant (hr⁻¹)

C = concentration of the substance (moles/liter)

BIOLOGICAL PROCESSES

Bioaccumulation

Bioaccumulation refers to the concentration of a substances in living

species. This is generally reported in terms of a bioconcentration factor (BCF), the ratio of the concentration of the substance in a living organism to the equilibrium concentration in the medium in which the organism lives. Concentrations in the two phases are usually expressed in the same units. Bioconcentration factors reported in the literature generally range from one to one million.

Biotransformation/Biodegradation

Biotransformation and biodegradation refer to the transformation and breakdown, respectively, of chemical compounds by natural biological processes. The resulting products range from simple organic substances to inorganic compounds. This fate process is important in aquatic systems and soils, and plays a significant role in wastewater treatment. Biotransformation/biodegradation is generally expressed as a pseudo first order process as indicate below:

$$R_B = K_B C$$

where R_B - rate of biological transformation/degradation (moles/liter-hr)

K_B - pseudo first order rate constant (hr^{-1})

C - substance concentration in the medium (moles/liter)

OCTANOL/WATER PARTITION COEFFICIENT

The octanol/water partition coefficient (K_{ow}) is defined as the ratio of a chemical's concentration in the octanol phase to its concentration in the aqueous phase of a two phase octanol/water system. K_{ow} values for organic chemicals have been measured as low as 10^{-3} and as high as 10^7 . K_{ow} is correlated to solubility, soil/sediment adsorption coefficient, and bioconcentration factors making the K_{ow} value very important in evaluating the

environmental fate of organic chemicals. The octanol/water partition coefficient represent the tendency of a chemical to partition itself between an organic phase (such as fish, soil) and aqueous phase. In general, chemicals with low K_{ow} (< 10) may be considered relatively hydrophilic. Such substances generally have high water solubilities, small soil/sediment adsorption coefficients, and low bioconcentration factors. Substances with high K_{ow} values ($> 10^4$) are very hydrophobic and have low water solubilities, high soil/sediment adsorption coefficients, and high bioconcentration factors.

APPENDIX C

GLOSSARY OF TOXICOLOGICAL TERMINOLOGY

APPENDIX C

GLOSSARY OF TOXICOLOGICAL TERMINOLOGY

1. Test Duration

- o Acute studies involved a single dose or, for inhalation or aquatic studies, a relatively brief exposure of up to 96 hours. Results are usually expressed as an LD50, median lethal dose, or LC50, median lethal concentration, the calculated amount which would kill half of all dosed animals. For other endpoints, a comparable EC50 (median effective concentration), IC50 (median incapacitating concentration) or other such term may be calculated.
- o Subchronic studies involve repeated doses for up to 3 months.
- o Chronic studies involve repeated doses for longer period, often for most of a lifetime or about 2 years for rats and mice.

2. Routes

- o Ingestion or oral studies are those in which the dose is given by mouth. It may be in the feed or water or given by gavage (through a tube inserted into the stomach).
- o Inhalation studies are those in which the dose is given in the air. Also included here is intratracheal instillation, in which the dose is given by a tube into the lung.
- o Dermal studies involve applying the test compound to the skin; inhalation studies include some dermal exposure.
- o Parenteral studies are those in which the dose bypasses the lung and gastrointestinal tract. Common varieties include subcutaneous (given under the skin by needle), intra-muscular (injected into the muscle, as with most immunizations), intravenous (into a vein), and intraperitoneal (into the peritoneal cavity between the abdominal muscular wall and the internal organs). Except for snake bites and similar phenomena, parenteral dosing is not seen environmentally.
- o In vivo tests are done in "live" animals.
- o In vitro tests are done "in glass" on isolated organs, cells, or sub-cellular fractions and are, therefore, relatively removed from the natural state.

3. Endpoints

- o Neurotoxicity refers to effects of toxic substances on various structures of the nervous system. The effects may involve direct damage to structures including axons of peripheral neurons, myelin, and junctions, among others. Manifestations of neurotoxicity include acute toxic effects such as muscular twitching, weakness, convulsions, and respiratory paralysis. Delayed neurotoxicity may result from direct action of the toxic substance through axon degeneration followed by demyelination of tracts in the spinal cord or peripheral nerves with resultant paralysis.

- o Behavioral toxicity refers to changes in adaptive behavioral capacity that result from the effects of toxic substances on the neural system. Changes may occur in such behavioral functions as acquisition of skills, learning, short- and long-term memory, decision-making, and psychomotor functioning.
 - o Hepatotoxicity is adverse effects in the morphology and/or functions of the liver. Some common endpoints of chemical injury include the following:
 - Accumulation of abnormal amounts of hepatic lipid, especially triglycerides
 - Inhibition of protein synthesis
 - Lipid peroxidation of hepatic microsomes
 - Necrosis
 - Cholestasis
 - Cirrhosis
 - Carcinogenesis
 - o Renal Toxicity (also called nephrotoxicity) is adverse effects in the morphology and/or functions of the kidney. Some manifestations of renal toxicity include depression of creatine clearance, phosphate reabsorption, and tubular degeneration.
 - o Blood Toxicity refers to chemically-induced alternation in components of the blood by influencing their production in the hematopoietic system, rate of peripheral destruction, or distribution. Anemia is a decrease in erythrocytes (red blood cells), in hemoglobin (the red-colored protein which carries oxygen), or in both. Aplastic anemia is a severe form characterized by failure of the bone marrow to form any cells. Hemolytic anemia is caused by destruction of erythrocytes. Hemorrhagic anemia is caused by loss of blood. Leukopenia is a decrease in leukocytes (white blood cells).
 - o Teratology may be defined as the study of permanent structural or functional abnormalities arising during embryogenesis. These abnormalities are generally incompatible with, or severely detrimental to, normal post-natal survival or development.
 - o Reproductive toxicity refers to detrimental effects on reproduction and on the offspring following parental exposure. Manifestations of reproductive toxicity include impaired fertility, fetal death, and birth or developmental defects. Reproductive toxicology includes teratology.
 - o Mutagenicity is the capacity to cause inheritable changes in the genetic makeup of a cell. Manifestations of mutagenic effects include point mutations, numerical aberrations, and structural aberrations.
 - o Carcinogenicity refers to the ability of a chemical to significantly increase the incidence of malignant lesions in animals or humans, induce rarely-occurring tumors, or significantly decrease the latency period for tumor development relative to an appropriate background of control group.
4. Pathological Terms
- o A tumor or neoplasm is a "new growth" of cells multiplying in an uncontrollable, progressive manner. The process is called neoplasia. Tumors are divided into benign and malignant, with the latter being cancer. Types seen include:

- Adenomas - benign tumors from glandular tissue; adenocarcinomas are malignant tumors from glandular tissue.
 - Lipomas - benign tumors from fat tissue
 - Carcinomas - malignant tumors from epithelium (the covering tissue of the internal and external surfaces of the body).
 - Lymphomas malignant tumors from lymph tissue
 - Sarcomas - malignant tumors from connective and related tissues. Subtypes include fibrosarcomas from fibrous tissue, hemangiosarcomas (or angiosarcomas) from the lining of blood vessels, lymphosarcomas from lymph tissue, myxosarcomas from muscle tissue, and osteosarcomas from bone tissue.
 - Teratomas - tumors containing many different types of cells.
- o Non-tumorous growth irregularities include:
 - Hyperplasia - an abnormal increase in the number of cells
 - Hypertrophy - an abnormal increase in the size of cells
 - Hypoplasia - decreased size of an organ
 - Aplasia - lack of development of an organ
 - Anaplasia - growth of undifferentiated cells.
 - o Pneumoconiosis is a lung condition caused by the permanent deposition of substantial amounts of particles in the lung and the tissue reaction to this deposition. Some types, such as anthracosis (from coal dust) and siderosis (from iron or rust inhalation) are relatively mild, unless extreme (as in "coal workers pneumoconiosis," called "black lung" by legislators). Other types such as asbestosis (from asbestos), and silicosis (from sand as used in grinding wheels, sandblasting, and similar activities) are generally serious diseases.

5. Miscellaneous Terms

- o Neuropathy is a syndrome of neurotoxicity. This term emphasizes the recognition of a group of effects as having a single cause, whether than cause is known or not. Central neuropathies affects the central nervous system (the brain and spinal cord), while peripheral neuropathies affect the peripheral nervous system (the entire nervous system except the brain and spinal cord).
- o Chelation therapy is a method for ridding a patient of a toxin by giving doses of a cheating agent which binds tightly to the toxicant and is then excreted, carrying the toxicant with it. It is commonly used for metal intoxications.
- o Homeostasis is the general term for the organism's structures and mechanisms for maintaining a constant internal environment - normal temperature, oxygen levels, blood cell concentrations, and so on.
- o Anesthesia is a loss of feeling and sensation, especially the loss of the sensation of pain. It is deliberately induced before surgery, either as

general anesthesia, a state of unconsciousness, or as local anesthesia, confined to the target area.

- o General central nervous system depression is a well-know syndrome characterized by light-headedness, giddiness, inebriation, unconsciousness, and death. It is produced by most organic solvents; when produced by ethanol, it is commonly called drunkenness.
- o Chloracne is an acne-like eruption on the skin cause by chlorinated organic compounds
- o Osteomalacia is a condition characterized by softness of the bones due to inadequate mineral deposition, with symptoms of pain, muscular weakness, and frequent fractures, even from ordinary movement. It is caused by failure to lay down the minerals. Osteoporosis is a weakening of the bones caused by a reduction in mineral content; it is most common in post-menopausal women.
- o Acroosteolysis or osteolysis, is bone dissolution of the tips of the fingers and toes.
- o Scleroderma is a chronic hardening and thickening of any connective tissue, especially the skin.
- o Raynaud's disease, also called Raynaud's syndrome, is a vascular disease consisting of intermittent attacks of pallor of the fingers and toes, and occasionally the ears and nose, brought on by cold or emotion. There are many known causes, including exposure to vibration, poisoning with lead, arsenic, and ergotamine, and primary pulmonary hypertension. In many cases, no cause is apparent.
- o Edema is the accumulation of fluid. It may be subcutaneous edema, under the skin in most areas of the body, or it may be localized in the lower extremities or elsewhere.

APPENDIX D

**CALCULATION OF GEOMETRIC MEAN CONCENTRATIONS
FOR INDICATOR CHEMICALS**

APPENDIX D

CALCULATION OF GEOMETRIC MEAN CONCENTRATIONS FOR INDICATOR CHEMICALS

Samples were collected from four environmental media during the remedial investigation: soil, ground water, surface water, and sediment. PRC divided the sample locations for each medium into the following categories:

- o Soil
 - Background locations west of the Sciota River
 - Agricultural fields west and north of Bowers Landfill
 - Sampling locations on or adjacent to the landfill
- o Groundwater
 - Upgradient monitoring wells
 - Downgradient monitoring wells
 - Residential wells (upgradient from the landfill)
- o Soil, Sediment
 - Upstream locations from the Sciota River
 - Downstream locations from the Sciota River
 - Drainage ditches and a quarry adjacent to the landfill

PRC calculated geometric mean concentrations for indicator chemicals for each category listed above. PRC followed several general guidelines in calculating geometric means. These are listed below.

- o PRC did not calculate a geometric mean for an indicator chemical within a group of samples if the chemical was not detected. For example, benzene was not detected in ground-water samples collected from upgradient wells, so a geometric mean was not calculated.
- o PRC did not include any data that was not considered quantitatively accurate when calculating geometric means. All data that were reported with the following qualifiers were excluded from the calculations: N, *, M, and B. (See Appendix A for definitions of these qualifiers.) For example, mercury was detected in two upgradient monitoring well samples -- wells W-4 and P-4A. However, both results were qualifiers with an N, so a geometric mean was not calculated.
- o PRC included data that was qualified, but considered quantitatively accurate, when calculating geometric means. All data reported with the following qualifiers were included in the calculations: E, J, [], and S. For example, tetrachloroethene was found in two downstream

surface water samples; both results were qualified with a J. PRC calculated a geometric mean using these results.

- o PRC indicated non-detected results in the calculations of geometric means if the results were not qualified with N, *, M, or B.

The geometric mean is defined as the average of the logarithms for a series of numbers. Because the logarithm of zero (0) is undefined, non-detected results had to be assigned a numerical value. Table D-1 summarizes the numerical values that PRC used to represent non-detected results. In general, PRC assigned a numerical value equal to one-half the practical detection limit for an indicator chemical. We have defined the practical detection limit as the lower of the following two numbers:

- o The Contract Laboratory Program (CLP) contract-required detection limit (CRDL) for a indicator chemical
- o The lowest reported concentration for an indicator chemical or for a chemical similar to the indicator chemical

For example, the CRDL for tetrachloroethene in surface water is 5 ug/L. However, tetrachloroethene was detected in surface water samples at concentrations as low as 1.0 ug/L. Thus, the practical detection limit for tetrachloroethene in surface water samples was set at half of this lower value, a 0.5 ug/L. In calculating geometric mean concentrations for tetrachloroethene in surface water, all non-detected results were assigned a value of 0.5 ug/L.

TABLE D-1

**SUMMARY OF CONCENTRATIONS USED TO REPRESENT
NON-DETECTED VALUES IN CALCULATING GEOMETRIC MEAN
CONCENTRATIONS FOR INDICATOR CHEMICALS**

<u>Environmental Medium</u>	<u>Indicator Chemical¹</u>	<u>Contract-Required Detection Limit²</u>	<u>Lowest Reported Concentration for Indicator Chemical or for Similar Chemicals</u>	<u>Representative Value⁴ for Non-detects</u>
Soil	Chlordan	100.0 ug/kg	20.0 ug/kg	10.0 ug/kg
	PCB	100.0 ug/kg	300.0 ug/kg ₅	50.0 ug/kg
	PAH	400.0 ug/kg	41.0 ug/kg	20.0 ug/kg
Ground Water	Lead	2.2 ug/L	6.9 ug/L	1.1 ug/L
	Benzene	5.0 ug/L	1.3 ug/L	0.6 ug/L
	Tetrachloroethene	5.0 ug/L	1.3 ug/L	0.6 ug/L
Surface Water	Lead	2.2 ug/L	6.6 ug/L	1.1 ug/L
	Mercury	0.2 ug/L	0.2 ug/L	0.1 ug/L
	Tetrachloroethene	5.0 ug/L	1.0 ug/L	0.5 ug/L
	PCB	1.0 ug/L	1.2 ug/L	0.5 ug/L
Sediment	Mercury	0.12 mg/kg	0.1 mg/kg	0.05 mg/kg
	Chlordan	100.0 ug/kg	120.0 ug/kg	50.0 ug/kg
	PCB	100.0 ug/kg	420.0 ug/kg	50.0 ug/kg
	4-Methylphenol	500.0 ug/kg	49.0 ug/kg	25.0 ug/kg
	PAH	500.0 ug/kg	49.0 ug/kg	25.0 ug/kg

Notes:

- ¹ An indicator chemical is not listed if (1) it was detected in all samples from an environmental medium or (2) if it was not detected in any samples from the medium.
- ² Contract required detection limits (CRDL) varied slightly for different sampling rounds. For example, the CRDL for chlordane in soil ranged from 87 ug/kg to 120 ug/kg. In these cases, a typical value was chosen.
- ³ Similar chemicals for organic indicator chemicals are defined as follows:
 - Chlordane -- other pesticides
 - PCB -- all PCB isomers
 - Benzene, tetrachloroethene -- other volatile organic compounds
 - 4-Methylphenol, PAH -- other semivolatile organic compounds
- ⁴ Representative value is half the lower value from the two previous columns.
- ⁵ U.S. EPA split soil samples reported lower concentrations for several semivolatile organics. However, these samples comprise approximately 8 percent of the data set and are not considered representative.